1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this report is to assess the mineral resource occurrence and development potential of all lands managed by the U.S. Bureau of Land Management's (BLM's) Price Field Office in Carbon and Emery Counties, Utah. This assessment involved reviewing both published and unpublished data, and selecting pertinent information for use in the report. Identified mineral resources are classified according to the BLM system described in Manual 3031 (BLM, 1985) and Manual 3060 (BLM, 1994). As used in this report, the term mineral includes any earth material that is considered an economic commodity.

The Price Field Office is currently revising and combining the Price River Resource Area Management Framework Plan (MFP), and the San Rafael Resource Management Plan (RMP), into a new management plan to be called the Price Field Office RMP. As part of the RMP, the BLM is required to prepare a Mineral Potential Report describing the occurrence and development potential of economic mineral commodities in the planning area. Once complete, this Mineral Potential Report will become incorporated into the broader RMP to provide decision makers with a better understanding of the mineral resources in the area, and the importance of those resources in the context of future land use allocations. Prior to the restructuring of the BLM in the mid-1990's, the northern portion of the planning area was previously managed as the Price River Resource Area, while the southern area was designated the San Rafael Resource Area. The Price River Resource Area MFP (BLM, 1982a) was approved in 1983 and supplemented in 1989. The San Rafael RMP (BLM, 1987) was approved in 1991. Both of these documents are still in effect, but are being revised under the Price Field Office RMP.

This report provides an intermediate level of detail for mineral assessment as prescribed in BLM Manual 3031, and did not include field studies for data collection. This report is prepared as a preliminary mineral assessment for use in an Environmental Impact Statement (EIS) and a Management Situation Analysis (MSA) as required by the National Environmental Policy Act (NEPA) for amending existing management plans. This report is not a decision document, and does not present specific recommendations as to which lands should be open for mineral claims or leases, or which (if any) lease stipulations should be modified. Specific recommendations concerning land use planning issues will be included in the EIS.

The Utah Geological Survey (UGS), the BLM, and the U.S. Geological Survey (USGS) are currently working on a National Coal Resource Assessment (NCRA) project to determine the amount of coal remaining for future development in Carbon and Emery Counties. The BLM has determined that the results of this project will become incorporated into this Mineral Potential Report as soon as they are available.

Attachment 4 of this document has been reserved for the inclusion of coal resource and development potential information. However, because a description of coal bearing strata in the planning area provides necessary background information for the assessment of other mineral resources, particularly coal bed methane, a brief discussion of coal occurrence will be included in this report.

The UGS is currently preparing a geologic report titled Energy, Mineral, and Ground-Water Resources of Carbon and Emery Counties, Utah (UGS, 2002a). This document (in press) is scheduled for publication sometime in late 2002, and is similar in scope to this mineral report but more detailed and comprehensive. Accordingly, it is anticipated that this document and the UGS report will be used in conjunction for future land use planning decisions.

Throughout this document, a variety of maps are referenced in the text and presented in the rear of the report. These graphics were prepared using a variety of sources including:

1. The Utah State BLM's "Premier" Geographic Information System (GIS) coverages (BLM, 2002b).

2. GIS coverages obtained from the BLM's Moab, Utah Field Office (BLM, 2002).

3. The Digital Geologic Resource Atlas of Utah (UGS, 1999a).

4. The Digital Geologic Map of Utah (UGS, 2000).

5. The Automated Geographic Reference Center (AGRC) and the Commodity Resource Information Board (CRIB) data available through the State of Utah's Internet web site (UGS, 2002).

6. Figures and plates from the UGS mineral report (UGS, 2002a).

7. Direct reproductions from other published sources.

In general, the map scales of the original figures that were used to generate the graphics in this report ranged from 1:24,500 to 1:500,000. Most of the BLM's GIS coverages, and AGRC and CRIB data are on a scale of either 1:24,500 or 1:100,000. However, because the Metadata files in these coverages are often incomplete, it is sometimes not possible to determine the original scale of the source map. Other map sources such as the digital Geologic Map of Utah (UGS, 2000) were originally published on a scale of 1:500,000.

1.2 LANDS INVOLVED AND RECORDS DATA

Carbon (947,632 acres) and Emery (2,850,356 acres) Counties together comprise 7.2 percent of the total Utah land area. As described in the Statement of Work (SOW) for the Price Field Office RMP Revision and EIS (BLM, 2001), the planning area for this report includes all of the publicly owned land and federal mineral estate managed by the BLM's Price Field Office in Carbon and Emery Counties, Utah (Map 1). This area includes a total of approximately 3,700,000 acres of land, which represents slightly over 97 percent of the total land area of Carbon and Emery Counties combined. For this reason, the term planning area as used in this report is generally considered synonymous with the total land area of Carbon and Emery Counties.

The BLM Price Field Office directly administers approximately 2,550,000 acres of federal land within Carbon and Emery Counties (BLM, 2001). In addition, the BLM State Office in Salt Lake City manages the subsurface mineral estate located within the Manti-La Sal and Fishlake National Forests, along with some lands administered by the National Park Service (i.e., Capitol Reef National Park) and private landowners. Also included in the planning area are recently acquired lands west of the Green River that were previously part of the Naval Oil Shale Reserve #2 (NOSR2), along with a ¼ mile scenic easement on the east side of the Green River in Uintah County (about 6,500 acres)(BLM, 2001). The land surface management status of the planning area is shown on Map 2.

Over half of the surface acreage in Carbon County, and 20 percent of the surface acreage in Emery County is not held by the federal government. This non-federal land belongs to either private landholders (including individuals and corporations), or lands held by the Utah School and Institutional Trust Lands Administration (SITLA)(Map 2). Much of this land is, or could be, available for lease or purchase under conditions set by the owner. While mineral leases on private land generally require negotiation with the owner, leases on state land (including rental and/or royalty payments) are more standard, but vary somewhat according to the commodity type (UGS, 2002a).

There are a total of 10 Wilderness Study Areas (WSAs) and one Instant Study Area (ISA) within the Price Field Office. These WSAs are listed in Table 1 and are shown on Map 3. Only the U.S. Congress can take action on designating these areas as wilderness.

Table 1. Price Field Office Wilderness Study Areas

WSA Name	Acreage
Desolation Canyon	207,775
Turtle Canyon	33,690
Jack Canyon	7,500
Link Flats ISA	912
Muddy Creek	31,400
Sid's Mountain/Sid's Cabin	80,970
Devils Canyon	9,610
Crack Canyon	25,315
San Rafael Reef	55,540
Horseshoe Canyon	18,580
Mexican Mountain	59,600
Total	**530,892**

Source: BLM Price Field Office

In addition to the formal WSAs, there are many areas within the Price Field Office that have been inventoried for wilderness characteristics by both the BLM and citizens groups such as the Utah Wilderness Coalition. As directed by the Secretary of the Interior, the BLM undertook a comprehensive review of these lands that resulted in the 1999 publication of the document titled Utah Wilderness Inventory (BLM, 1999a). This document was later released for public comment, and the wilderness inventory areas were subsequently reassessed for study in the Price RMP. Changes to the wilderness inventory boundaries were primarily due to improved mapping, the elimination of state land sections along unit perimeters, field reevaluations, and the exclusion of certain vehicle routes. Acreage changes to the wilderness inventory areas are listed in Table 2.

Table 2. Wilderness Inventory Acreage Summary

Inventory Area	Wilderness Character Acres Identified in the 1999 Utah Wilderness Inventory	Wilderness Character Acres Forming the Planning Baseline for the Price RMP
Cedar Mountain	15,100	14,984
Desolation Canyon*	84,635	86,453
Devils Canyon	8,800	10,895
Hondu Country	20,200	20,104
Jack Canyon	3,300	3,331
Labyrinth Canyon*	26,221	26,170
Mexican Mountain	36,700	40,911
Muddy Creek-Crack Canyon*	119,867	125,709
Mussentuchit Badlands**	3,900	24,984
San Rafael Reef	37,600	45,868
Sids Mountain	23,300	35,109
Turtle Canyon	4,860	4,861
Upper Muddy Creek	18,100	17,852
Wild Horse Mesa*	20,129	26,625
Total	**442,712**	**483,856**

Source: Price Field Office, Revisions to the 1999 Utah Wilderness Inventory
*Acreage figures apply only to the lands administered by the Price Field Office
** Includes 701 acres in Sevier County/Richfield Field Office

On January 28, 2002, Governor Mike Leavitt announced that he would formally ask the Bush administration to declare 620,000 acres in south-central Emery County as "San Rafael Western Heritage National Monument." The Emery County Commission is currently submitting a proposal to Governor Leavitt to be presented to President George W. Bush for declaration under the Antiquities Act. To date, no decision has been made by Congress on the status of the wilderness areas or the National Monument. Until that decision is made, all WSAs are managed under the Interim Management Policy for Lands Under Wilderness Review (BLM Manual H-8550-1). Other lands have been proposed as wilderness areas various citizens groups, but are currently managed as normal BLM lands (UGS, 2002a).

In addition to the WSAs, there are currently 13 Areas of Critical Environmental Concern (ACECs) in the planning area (Table 3). An ACEC is defined in the Federal Land Policy and Management Act as an area where special attention is required to protect (among other things) important historic, cultural, scenic, or wildlife resources.

Table 3. Areas of Critical Environmental Concern

ACEC	Acres	Values
Big Flat Tops	295	Relict vegetation
Bowknot Bend	1,072	Relict vegetation
Copper Globe	128	Mining
Dry Lake Archaeological District	22,225	Archaeological, geologic
I-70 Scenic Corridor	45,522	Scenic
Muddy Creek	28,769	Scenic, mining, riparian
Pictographs	43	Archaeological

Table 3. Areas of Critical Environmental Concern

ACEC	Acres	Values
San Rafael Canyon	54,054	Scenic
San Rafael Reef	83,950	Scenic, relict vegetation
Segers Hole	7,933	Scenic
Sids Mountain	61,381	Scenic
Swasey Cabin	60	Historic ranching
Temple Mountain Historic District	2,444	Mining

Source : Utah BLM

Most of the private land in Emery County is located along the major roads in the western part of the county (i.e., Castle Valley), while most of the private land in Carbon County is around the towns of Price, Helper and Wellington, and as several large parcels in the Book Cliffs and northern Wasatch Plateau coal field. State land is scattered throughout both counties, and in several large consolidated parcels. Federal land comprises the remainder, with National Forests in the western portion of both counties on the Wasatch Plateau. A small portion of Capitol Reef National Park is extends into the extreme southwest corner of Emery County (Map 2).

In most situations, the mineral estate for a given piece of property belongs to the surface estate, but some tracts have split ownership. For most lands with split ownership, the mineral rights (or partial mineral rights) have been retained by the SITLA, and the surface rights are privately held, or belong to the U.S. Forest Service (UGS, 2002a).

The BLM is the main federal administering agency for oil and gas, minerals (locatable, leasable and salable) and coal development in the planning area. Table 4 lists the acreage held under current oil and gas leases, current coal leases, and active mining claims (locatable minerals) on federal land in the planning area.

Table 4. Land Held for Mineral and Energy Resources in Carbon and Emery Counties.

Resource	Carbon County	Emery County	Total
Oil and Gas Leases	238,053 acres	251,072 acres	489,125 acres
Coal Leases	318,681 acres	354,708 acres	673,389 acres
Mining Claims	11,000 acres (approx.)	21,000 acres (estimated)	32,000 acres

Source: (UGS, 2002a)
Note: Information current as of September 30, 1999

Categorization of mineral resources as “locatable,” “leasable,” or “salable” are based upon the provisions of the Act of May 10, 1872, otherwise known as the General Mining Law of 1872. This Act declared “all valuable mineral deposits in lands belonging to the United States…to be free and open to exploration and purchase.” The federal regulations further defined a “locatable mineral” or a “valuable mineral” as being whatever is recognized as a mineral by standard authorities (whether metallic or otherwise) when found in public lands in quantity and quality sufficient to render the lands valuable.

Whether or not a particular mineral deposit is locatable depends on such factors as quality, quantity, mineability, demand, and marketability. Over time, the number of locatable minerals authorized by the General Mining Law of 1872 has been substantially reduced by several subsequent congressional acts, primarily:

1. The Mineral Leasing Act of 1920, as amended
2. The Materials Act of July 31, 1947, as amended

The Mineral Leasing Act of 1920, as amended, authorized that deposits of oil, gas, coal, potassium, sodium, phosphate, oil shale, native asphalt, solid and semi-solid bitumen and bituminous rock, and oil impregnated rock/sand, may be acquired through a mineral leasing system. The Materials Act of 1947 further excluded common varieties of sand, stone, gravel, pumice, cinders, clay, humate and petrified wood from claims staking. However, uncommon varieties of these materials (such as specialty clays) may be retained as locatable minerals. Those minerals considered non-locatable generally have a normal quality, and a value of ordinary use.

The extraction and sale of aggregate materials are governed by the Mineral Materials Disposal Regulations codified in Title 43 of the Code of Federal Regulations, parts 3600 through 3622 (43 CFR 3600-3622). These regulations allow for mineral materials disposal through either mineral materials sales or non-exclusive disposal. Mineral material sales can be made on the initiative of an authorized BLM officer, or can be made subsequent to receipt of a request to purchase by an applicant. Sales can be made under a competitive bid basis, or under a non-competitive basis subject to certain volume or weight limitations. Non-exclusive disposal of mineral materials can occur through sale or "free-use," and can be made from the same deposit within areas identified by the BLM officer. These areas are designated as community pit sites (generally defined sites) or common-use areas (generally a broad geographic area). The differentiating factor between a community pit site and a common-use area is that designation as a community pit constitutes a superior right to remove the material against any subsequent claim or entry to the lands, whereas designation as a common-use area does not constitute a superior right. In either case, common-use areas/community pits are for noncommercial use and generally require a permit. Mineral material may be disposed of through "fair market value" sales from either community pits or common-use areas. In addition, free-use permits (FUPs) can be issued to any federal, state, or local government agency, or non-profit organization.

As described in BLM Manual 1624, federal oil and gas leases (including coal bed methane) fall into one of four categories that become increasingly restrictive (BLM, 1986):

1. <u>Open Subject to Standard Lease Terms and Conditions</u>: These are areas where it has been determined through the planning process that the terms and conditions

of the standard lease form are sufficient to protect other land uses or resource values.

2. Open Subject to Seasonal or Other Minor Constraints: These are areas where it has been determined that moderately restrictive lease stipulations may be required to mitigate impacts to other land uses or resource values. Category 2 leases frequently involve timing limitations such as restricting construction activities in designated Big Game Winter Ranges, or controlled surface use stipulations such as creating a buffer zone around a critical resource.

3. Open Subject to No Surface Occupancy or Other Major Constraint: These are areas where it has been determined through the planning process that highly restrictive lease stipulations are necessary to protect resources. Category 3 leases may prohibit the construction of well production and support facilities. These areas can be subject to directional drilling.

4. Closed to Leasing: These are areas where it has been determined that other land uses or resource values cannot be adequately protected, and appropriate protection can only be ensured by closing the land to leasing through either statutory or administrative requirements.

Lands within the planning area that are covered by each of the four oil and gas leasing categories are shown on Map 4 (BLM, 2002). The information on Map 4 is current as of September 21, 2001, and includes: 2,496,349 acres under Category 1 (66% of planning area); 890,290 acres under Category 2 (23% of planning area); 213, 887 acres of Category 3 leases (6% of the planning area); and, 202,942 acres under Category 4 (5% of the planning area). As shown on Map 4, most of the Category 4 oil and gas leases in the planning area are WSAs located in the San Rafael Swell region of Emery County. These include the Mexican Mountain, Sid's Mountain, San Rafael Reef, Devils Canyon, Muddy Creek and Crack Canyon Wilderness Study Areas. Additional lands currently closed to oil and gas leasing include areas immediately west of the Green River in Carbon and Emery Counties included as part of the Desolation Canyon, Jack Canyon, and Turtle Canyon WSAs (Maps 3 and 4). Environmental considerations and land use planning activities can trigger stipulations that modify the terms of the lease. Specific lease stipulations for a given area are determined through the EIS process by land use planning agencies such as the BLM. While the BLM is responsible for oil and gas leasing and the permitting of drilling operations, UDOGM regulates the permitting, spacing and production of gas wells, and the disposal of water. There are currently 895 active (or recently active) oil and gas leases in the planning area. These leases are shown on Map 5 (BLM, 2002). Seismic surveys are a critical part of oil and gas exploration, and are authorized on BLM managed land by approval of Notices of Intent to Conduct Geophysical Operations (NOIs). Although originally located as placer mining claims under the General Mining Law of 1872, tar sand deposits are now available under the Combined Hydrocarbon Leasing Act of 1981. Oil shale is specifically excluded from combined hydrocarbon leases (along with coal and gilsonite).

In addition to oil and gas leases, there are currently 106 coal leases in the planning area, along with 620 subdivisions (consisting of 160 acres or ¼ sections) that contain federal mining claims (BLM, 2002b). These are shown on Maps 6 and 7, respectively. In addition, the locations of active and permitted mines in Carbon and Emery Counties (as of 12/31/01) are shown on Map 8. For locatable minerals, the existing Price River and San Rafael management plans recommend that 82 percent planning area (excluding USFS and NPS lands) be available for location with standard conditions, and 18 percent be available with special conditions (UGS, 2002a). Only 1,780 acres were closed to mineral entry, mostly to protect riparian zones, aquatic areas, or ACECs. As noted above, the existing RMPs do not cover National Forest or National Park lands which are administered by the state BLM office.

Private individuals such as rockhounds may take small amounts of rocks and minerals from unrestricted federal lands without obtaining a permit if collection is for personal, non-commercial purposes. Collection in large quantities or for commercial purposes requires a permit, lease or license from the Price Field Office (UGS, 2001b). Mineral material disposal regulations allow that persons may collect limited quantities of petrified wood (up to 25 pounds per day with a yearly limit of 250 pounds) for non-commercial purposes (i.e., free-use) under the terms and conditions consistent with the preservation of significant deposits as a public recreational resource (43 CFR 3622). In this regard, petrified wood is considered to be not only a salable mineral, but also a paleontological resource, and may be subject to additional protective measures, the conditions of which are typically specified in the EIS.

2. DESCRIPTION OF GEOLOGY

As described in BLM Manual 3060, this section of the Mineral Potential Report discusses the geology of the area on both a regional and site-specific basis. However, due to the large size of the "site" or planning area (e.g., approximately 3.7 million acres) the discussion of regional geology will include the entire State of Utah, along with adjacent parts of Colorado and New Mexico, as necessary. For both the region and the planning area, discussion topics will include (as appropriate) physiography, rock units (lithology and stratigraphy), structural geology and tectonics, geophysics and geochemistry, and historical geology.

2.1 REGIONAL GEOLOGY

This section of the report discusses the geology of the region, which includes the Colorado Plateau, and portions of adjacent physiographic provinces.

2.1.1 Physiography

Carbon and Emery Counties are located in east-central Utah, and lie entirely within the Colorado Plateau physiographic province. Overall, the Colorado Plateau covers some 130,000 square miles between the Rocky Mountain and Basin and Range provinces, and is characterized by relatively flat lying sedimentary rock strata uplifted to elevations between 5,000 and 10,000 above sea level (Hunt, 1974). Outstanding physiographic features of the Colorado Plateau include:

- Extensive sedimentary formations representing a rock record from Precambrian through Tertiary time (e.g., the Grand Staircase).
- Extensive areas of nearly horizontal sedimentary rock uplifted as much as two to three miles since the Cretaceous Period.
- Structural upwarps that form striking topographic features.
- Various igneous structures, mostly of Cenozoic age, characterized mainly by intrusive laccoliths, stocks and dikes in the interior of the plateau, and volcanic centers around the perimeter.
- A drainage system that is deeply incised, most of which flows to the Pacific Ocean via the Colorado River.
- Extensive areas of exposed rock, with many areas displaying near 100 percent outcrop exposure.
- Aridity and shortage of water.

To the west of the Colorado Plateau lies the Basin and Range Province that covers an area of about 300,000 square miles (Hunt, 1974). The Basin and Range consists of roughly north to south trending, evenly spaced mountain ranges separated by broad, flat, alluviated desert basins. These basins are typically graben structures that resulted from extensional tectonics (i.e., normal faulting) in Cenozoic time. Altitudes in the basins vary from below sea level to around 5,000 feet, while the range crests are typically 3,000 to 4,000 feet above the valley bottoms. Despite the overall homogeneity of the topography due to recent faulting, the geology of the mountain ranges is varied and complex, and reflects a long history of crustal unrest. Valley bottom deposits include extensive areas of dry Pleistocene lake beds along with alluvial fans, Aeolian dunes, and rocky areas bordering mountain fronts.

To the east and north of the Colorado Plateau lies the Rocky Mountain Province extending some 10,000 miles from Alaska to Patagonia. This high mountain region forms the continental divide of the North America, and contains a variety of igneous, sedimentary and metamorphic rocks in diverse kinds of structural uplifts and basins. As a whole, the Rocky Mountain region is the watershed for approximately 25 percent of the United States including the semiarid grasslands of the Great Plains, and the desert regions of the Colorado Plateau and Great Basin (Hunt, 1974).

2.1.2 Rock Units

The general stratigraphy and geologic history of Utah are well summarized by Stokes (1986) and Hintze (1988) from which much of the following information has been obtained. In addition, various geologic maps published by the Utah Geological and Mineral Survey (UGMS, 1980) and the U.S. Geological Survey (USGS; 1987, 1988, 1990, 1991) provided invaluable information on lithology and stratigraphy for specific areas within the planning area. A generalized geologic map of Utah is shown on Map 9. As shown on Map 9, Utah rocks range in age from Precambrian through Quaternary, and include a variety of compositions and modes of origin.

Basement rocks in Utah vary in age from 2.5 billion to 1.5 billion years old, and consist predominantly quartzites, schists and gneisses that are unconformably overlain by a series of younger Precambrian rocks (UGMS, 1980). As shown on Map 9, Precambrian rocks are exposed along the length of the Uinta Mountains in northeast Utah (the inferred southern edge of the Archean continent); and in small, isolated areas scattered around the State (Hintze, 1988).

The Phanerozoic Era in Utah is characterized by a variety of predominantly sedimentary rocks that were deposited in diverse marine and terrestrial environments including restricted ocean basins, continental shelves, epeiric marine platforms, fluvial/deltaic systems and lacustrine basins. As shown on Map 9, the majority of the Paleozoic sedimentary rocks in Utah were deposited in marine environments, while

Mesozoic sedimentation includes both marine and non-marine deposits. Tertiary sedimentary rocks are exclusively of terrestrial origin reflecting the regional uplift of the area to elevations above sea level during the Laramide orogeny. Overall, clastic sedimentary rocks of Permian through Eocene age dominant the landscape in the Utah portion of the Colorado Plateau.

Details on the lithology and stratigraphy of the planning area are discussed in Section 2.2.2.

2.1.3 Structural Geology and Tectonics

The overall structure and geologic history of the Colorado Plateau and surrounding regions can best be understood through a series of events that have occurred over geologic time in response to tectonic episodes. Hintze (1988) identified nine distinct phases of geologic history that have contributed to the evolution of the Utah landscape:

1. Archean – Middle Proterozoic (3,000 – 1,000 m.y. ago): Development of Metamorphic Basement – Although poorly understood, the edge of the original Archean craton apparently ran east to west across northern Utah with mixed sedimentary and volcanic island-arc assemblages accreted later from the south.

2. Middle Proterozoic – Late Proterozoic (1,000 – 800 m.y. ago): Precambrian Rifting – Extension and normal faulting along the continental margin, and development of the Uinta aulacogen.

3. Late Proterozoic – Devonian (800 – 360 m.y. ago): Miogeoclinal Platform Development – Utah was a passive continental margin that extended into eastern Nevada. Marine (predominantly carbonate) sedimentation across Utah, the geometry of which was strongly controlled by a "hingeline" running north to south across the state. In pre-1970's literature, this hingeline was referred to as the "Wasatch Line," and represented the eastern limit of the miogeosynclinal belt (Kay, 1951). West of the hingeline, sedimentation kept pace with rapid subsidence resulting in thick lower Paleozoic deposits. East of the hingeline (including all locations within the planning area), thin deposits accumulated on a stable continental shelf.

4. Mississippian – Permian (360 – 250 m.y. ago): Development of Uncompahgre Highland and Paradox Basin – Although the marine sedimentation from the previous phase continued, uplift of the Uncompahgre highland in southwest Colorado and the associated sinking of the Paradox Basin in the Four Corners area were the dominant events during this time. Similar couplets of Late Paleozoic mountain uplift with adjacent basin formation occurred throughout the region, and extended east into Arkansas forming what is referred to as the Ancestral Rockies. In southeast Utah, this resulted in thick accumulations of

carbonate and clastic sediments containing thousands of feet of evaporite deposits.

5. <u>Triassic – Early Cretaceous (250 – 100 m.y. ago):</u> Nevadan Orogeny – The collision between the North American continent and allocthonous terrain to the west created highlands in eastern Nevada. Meanwhile, the Paradox Basin filled as the Uncompahgre highland was eroded away. Much of eastern Utah was occupied by broad, shallow basins (at or near sea level) in which clastic sediments of fluvial, eolian, and shallow marine origin accumulated. These deposits form many of the spectacular red bed formations to which the Colorado Plateau is famous. In central Utah, the Arapien Basin formed in which extensive evaporites were deposited in a restricted, shallow marine basin. The Lower Cretaceous was a time of depositional hiatus and erosion across most of eastern Utah.

6. <u>Late Cretaceous (100-66 m.y. ago):</u> Sevier Orogeny and Foreland Basin Development – Uplift, compressional tectonics, and thrust faulting created mountain highlands in western Utah; along with the development of a shallow marine basin (epeiric platform) to the east separated by a costal plain containing prograding fluvial/deltaic systems. High eustatic sea levels resulted in the deposition of quality hydrocarbon source rocks. Late Cretaceous time marks the final stage of marine sedimentation in Utah prior to the regional uplift of the Colorado Plateau and the Great Basin. Most of the coal and coal bed methane bearing formations in the planning area were deposited during this time.

7. <u>Paleocene – Eocene (66-37 m.y. ago):</u> Laramide Orogeny and Uinta Basin Development – Compressional tectonics uplifted the Rocky Mountains, and further elevated the Colorado Plateau and Great Basin. In many cases, anticlinal upwarps were coupled with the formation of adjacent lake basins such as with the Uinta Mountains/Uinta Basin. Lacustrine deposits (from Lake Flagstaff and Lake Uinta) filled the Uinta Basin with sediments from nearby mountain uplifts. Most of the tar sand and oil shale deposits in the planning area were formed during this time. The uplift of the San Rafael Swell, a double plunging anticline covering much of Emery County, was also formed during this time.

8. <u>Oligocene – Early Miocene (37-15 m.y. ago):</u> Explosive Volcanism and Igneous Activity – Extensive volcanism and intrusive igneous activity throughout the region. As previously noted, volcanic rocks tend to predominate around the perimeter of the Colorado Plateau, with intrusive bodies in the center.

9. <u>Late Miocene to Holocene (15 m.y. ago – Present):</u> Regional Uplift and Basin and Range Faulting – Regional uplift of the Colorado Plateau and Great Basin was rejuvenated during the Late Miocene, and continues through the present. This intensified the down cutting of the region's rivers to where they are deeply

entrenched in many canyons today. To the west, crustal extension and thinning resulted in the characteristic basin and range topography we see today in western Utah and Nevada.

Details of the geologic structure of the planning area (e.g., Carbon and Emery Counties) are provided in Section 2.2.3 of this report.

2.1.4 Geophysics and Geochemistry

The division between the Colorado Plateau and adjacent physiographic provinces is generally defined on the basis of observable geology and topography. However, these differences are also manifested in geophysical measurements of the crust and upper mantle including seismic, magnetic, electrical, and heat flow surveys. In general, the Great Basin is characterized by an anomalous upper mantle as compared to the adjacent Colorado Plateau, and consists of a Bouguer gravity low, low seismic mantle velocities, and high heat flow (Mihalasky, 2001). The crustal thinning beneath the Basin and Range Province is such that the Mohorovicic Discontinuity lies at depths between 15 and 18 miles beneath the Great Basin, and from 22 to 26 miles under the Colorado Plateau (Stokes, 1986). Furthermore, this transition takes place abruptly, and appears as a bulge or upwarp in the mantle along a zone corresponding to the Wasatch Line and intensified earthquake activity. This mantle upwarp has been identified from electrical and seismic data, and by thermal measurements.

2.1.5 Historical Geology

Aside from the geologic history of the Colorado Plateau as described in Section 2.1.3, the geology of the region is of particular historical significance due to the abundance of paleontological resources (both vertebrate and invertebrate), and for native American petroglyphs. Of particular note is the Upper Jurassic Morrison Formation unsurpassed for its abundance of dinosaur fossils and exposed in many areas across eastern Utah.

2.2 SITE GEOLOGY

This section of the report discusses the geology of the site, including all of Carbon and Emery Counties.

2.2.1 Physiography

As noted above, Carbon and Emery Counties are located in east-central Utah, and lie entirely within the Colorado Plateau physiographic province. In 1928, Fenneman subdivided the Colorado Plateau into six sections on the basis of observable geomorphic features (Fenneman, 1928). The majority of the planning area lies within the Canyon Lands section of the Colorado Plateau, while the northern half of Carbon County is in the Uinta Basin section, and the western edge of both Carbon and Emery

Counties are included in the High Plateau section. More recently, Stokes (1986) refined the physiographic sections within the State of Utah for the Colorado Plateau, Rocky Mountain and Basin and Range Provinces (Map 10). As shown on Map 10, Carbon and Emery Counties include four sections within the Colorado Plateau (the Book Cliffs/Roan Plateau, Mancos Shale Lowlands, San Rafael Swell, and Green River Desert), and one physiographic section that was considered transitional between the Colorado Plateau and Basin and Range (the Wasatch Plateau section). In addition, a very small section of the Circle Cliffs-Teasdale Anticline Section of the Colorado Plateau cuts the extreme southwest corner of the planning area (Map 11). A brief description of each physiographic section as described by Stokes (1986) is provided below.

Perhaps the dominant physical feature within the planning area is the San Rafael Swell occupying the majority of Emery County (Map 11). This feature is a large northeast trending upwarp approximately 75 miles long and 30 miles wide that is part of a much larger, double plunging anticline (e.g., dome) structure. This large, regional fold exposes rocks of Pennsylvanian through Cretaceous age (Map 9). Resistant beds of sandstone are exposed as hogbacks on the steeply upturned east and west flanks of the anticline, and are referred to locally as “reefs.” Although the physiographic feature of the swell, and the structural anticline are often considered the same because they locally coincide, the anticlinal structure extends underneath the Mancos Lowlands to the north, and greatly influences the topography around the Book Cliffs area (USGS, 1990). Three perennial rivers (the Muddy, San Rafael and Price) flow eastward across this structure into the Green/Colorado River system (Map 1).

Bordering the San Rafael Swell on the north, west, and northeast sides is the Mancos Shale Lowland section (Maps 10 and 11) including the so-called Castle Valley, Clark Valley, and Grand Valley. The Upper Cretaceous Mancos Shale is an easily eroded rock formation, and is exposed at the surface across much of this section resulting in relatively low lying areas. The landscape of the Mancos Lowlands is characterized by sloping, gravel covered pediments, rugged badlands, and flat bottom alluvial valleys (Stokes, 1988). Immediately southeast of the San Rafael Swell lies the Green River Desert Section of the Colorado Plateau characterized by Quaternary eolian deposits with scattered mesas and buttes of Jurassic bedrock exposed at the surface.

To the north of the Mancos Shale Lowlands lies the Book Cliffs/Roan Plateau section of the Colorado Plateau. This area constitutes the southern extension of the Uinta Basin where Upper Cretaceous and Lower Tertiary rocks rise upward from the north along the dip slopes of the basin to reach elevations of 8,000 to 10,000 feet. On their south end, these rocks are abruptly truncated in great erosional cliffs that descend to elevations around 5,000 in the Mancos Lowlands. The Book Cliffs are formed by Upper Cretaceous sandstones and shaly siltstones of the Mesaverde Group, including Blackhawk Formation, Castlegate Sandstone, and the Price River Formation. To the northeast of the Book Cliffs themselves lie the Roan Cliffs which are formed by the reddish-brown mudstone and sandstone beds of the Colton Formation (Paleocene-

Eocene). Still further to the northeast in Carbon County are other erosional rises including the West Tavaputs Plateau and the Bad Land Cliffs that expose the Eocene Green Giver Formation.

Along the west margin of the planning area is the Wasatch Plateau section transitioning between the Colorado Plateau and Basin and Range physiographic provinces (Stokes, 1986). Although the stratigraphy in the Wasatch Plateau section is very similar to that further east in the Colorado Plateau (i.e., the Book Cliffs), the area displays some features more typical of the Great Basin such as extensional tectonics and north-south trending normal faults. The steep eastern margin of the Wasatch Plateau is a continuation of the Book Cliffs escarpment, and is an erosional feature not related to faulting (Stokes, 1986).

The Circle Cliffs-Teasdale Anticline physiographic section lies in the extreme southwest corner of Emery County (Map 11). This anticlinal structure is similar to the San Rafael Swell but it is shorter, narrower, and its axis trends northwest (Stokes, 1986). The Waterpocket Fold is a spectacular monocline on the east flank of the structure in Capitol Reef National Park that exposes steeply dipping Triassic strata as hogbacks.

Overall, elevations across the planning area range from a high of 10,760 feet on East Mountain located in northwest Emery County, to a low of around 4,500 feet on the Green River in the southeast corner of Emery County. With the exception of a two square mile area located immediately northwest of Scofield Reservoir in the northwest corner of Carbon County, the entire planning area is drained by the Green and Colorado Rivers. This small area drains to Great Salt Lake via Soldier Creek and Utah Lake. The Green River forms the eastern boundary of the entire planning area (Map 1).

2.2.2 Rock Units

Within Carbon and Emery Counties, rocks and unconsolidated deposits of Pennsylvanian through Quaternary age are exposed on the surface. With the exception of some small Tertiary intrusive bodies, especially in the southwest corner of Emery County, all of these rocks are of sedimentary origin, and most were deposited in terrigenous clastic systems.

While Map 9 presents a generalized geologic map of Utah, Map 12 is a more detailed geologic map of the planning area and includes all of Carbon and Emery Counties. While each of these geologic maps show the rocks that are exposed at the surface, stratigraphic sections are needed to understand the subsurface geology at various locations. Accordingly, the numbers shown on Map 9 correspond to the locations of various stratigraphic sections as presented by Hintze (1988), and include five stratigraphic sections within the planning area (e.g., Sections 64, 65, 66, 67 & 81). Each of these five stratigraphic sections is reproduced in Attachment 1, and depicts the vertical rock sequence at each location from Precambrian basement to Quaternary alluvium. In addition, the explanation sheet that accompanies the geologic map of Utah (UGMS, 1980) is included as Attachment 2, and shows stratigraphic columns and cross sections at various locations across the state. The remainder of this section provides brief descriptions of the important geologic formations in the planning area from youngest to oldest (Hintze, 1988; Stokes, 1986; USGS, 1987, 1988, 1990, 1991):

1. Surficial Deposits: (Quaternary) Unconsolidated surface deposits of varying textures and colors including alluvium, colluvium, pediment mantle, eolian dunes, glacial drift; and deposits associated with landslides, slope-wash, alluvial fans, and terraces. Up to 200 feet thick.

2. Green River Formation: (Eocene) Lithologies include limestone, calcareous mudstone, siltstone, shale and sandstone; while color varies from light gray, brown, reddish brown to light green. This unit is laterally persistent, and part of one the largest lacustrine deposits in the world. The formation has been divided into at least five mapable members/facies, but nomenclature varies between different workers in different parts of the basin. Contains significant deposits of tar sand and oil shale. Gradational with the underlying Colton Formation. Up to 6,000 feet thick.

3. Colton Formation: (Eocene to Paleocene) Reddish brown to green mudstone and shaly siltstone interbedded with fine grain sandstone with minor limestone. Primarily of alluvial origin with marginal lacustrine and deltaic facies. 660-2,770 feet thick.

4. Flagstaff Limestone: (Paleocene to Upper Cretaceous) Reddish brown to grayish brown mudstone with interbedded calcareous siltstone, sandstone, limestone

   conglomerate (locally oolitic), and limestone with minor carbonaceous shale. Lacustrine origin. 200 to 1,100 feet thick.

5. Price River Formation: (Upper Cretaceous) Light gray to grayish/reddish brown sandstone with conglomerate and mudstone. In places, it is dividable into distinct mapable members. Generally forms cliffs and steep slopes. Uppermost unit of the Mesaverde Group. Fluvial origin. Zero to 1,200 feet thick.

6. Castlegate Sandstone: (Upper Cretaceous) Light gray to dark gray, quartz sandstone with some conglomerate. Commonly forms cliffs and steep slopes. Upper-middle unit of the Mesaverde Group. Fluvial origin. 130 to 500 feet thick.

7. Blackhawk Formation: (Upper Cretaceous) Dominantly light brown to light gray quartz sandstone with interbedded shaly siltstone, shale, carbonaceous shale and coal. Generally forms steep slopes. The most important coal bearing formation in Utah, and host to the Book Cliffs and Wasatch Plateau coal fields in the

planning area. Lower-middle unit of the Mesaverde Group. Deltaic deposit. 400 to 1,500 feet thick.

8. Star Point Sandstone: (Upper Cretaceous) Light brown to brown quartz sandstone with interbeds of shale and shaly siltstone. Lower unit of the Mesaverde Group. Beach sand and intermediate marine shale. 200 to 1,000 feet thick.

9. Mancos Shale: (Upper Cretaceous) Consists of six members as follows (in descending order): 1) Upper Part of the Blue Gate Member; 2) Emery Sandstone Member; 3) Main Body of the Blue Gate Member; 4) Garley Canyon Beds of the Emery Sandstone Member; 5) Ferron Sandstone Member; and, 6) Tununk Member. Overall, the Mancos Shale consists of a light to dark gray, bluish gray to light brown shale and shaly siltstone with interbedded very fine to fine grain sandstone. Generally erodes to flat lowlands and valleys with sandstone members forming low ledges and cliffs. Deposited on a shallow marine shelf transitional to delta plains. The Emery and Ferron Sandstone Members contain coal beds and were deposited in a paralic setting. The Ferron Sandstone and Tununk Members are petroliferous, while the Ferron hosts the Emery coal field in the planning area. Total thickness 2,300 to 6,100 feet.

10. Dakota Sandstone: (Upper Cretaceous) Tan to light brown, crossbedded, quartz sandstone with thin, discontinuous, carbonaceous seams. Petroliferous in places. Deposited in a beach to marginal marine/deltaic environment. Zero to 30 feet thick.

11. Cedar Mountain Formation: (Lower Cretaceous) Consists of two units: 1) an upper purple to gray mudstone with discontinuous sandstone lenses; and, 2) a lower gray, crossbedded, quartz rich, sandstone/conglomerate. Fluvial deposit. 160 to 3,330 feet thick.

12. Morrison Formation: (Upper Jurassic) Consists of the upper Brushy Basin Member (bluish gray, green and maroon/purple claystone and mudstone with some bentonite, sandstone and limestone beds) and the lower Salt Wash Member (light gray to reddish purple quartz sandstone with some conglomerate and interbedded mudstone. Hosts roll-front type uranium deposits, and contains dinosaur fossils. Stands as low cliffs or rounded ledges. Fluvial deposit. 350 to 400 feet thick

13. Summerville Formation: (Middle Jurassic) Reddish-brown shaly siltstone and sandstone with thin interbeds of gypsum. Stands as low cliffs. Tidal-flat deposit. 120 to 250 feet thick.

14. Curtis Formation: (Middle Jurassic) Light greenish gray to light brown quartz sandstone with some siltstone and conglomerate. Glauconitic. Forms ledges that act as resistant caps. Marine deposit. 75 to 250 feet thick.

15. Entrada Sandstone: (Middle Jurassic) Orangish brown to reddish brown sandstone. Nearshore eolian deposit. 200 to 300 feet thick.

16. Carmel Formation: (Middle Jurassic) Consists of two mapable units. The upper unit is a reddish brown shaly siltstone with gypsum and sandstone interbeds. That forms broad, intricately dissected slopes. The lower unit is a pale green to brownish gray and calcareous sandstone. Shallow marine to supratidal deposit. Total thickness 560 to 650 feet.

17. Navajo Sandstone: (Lower Jurassic to Upper Triassic) Light reddish brown to light gray, trough crossbedded quartz sandstone with a few limestone beds in the upper section. Stands as steep cliffs. Eolian deposit. 400 to 1,000 feet thick.

18. Kayenta Formation: (Upper Triassic) Lavender to reddish brown sandstone with some shaly siltstone and conglomerate. Forms benches and steep slopes. Well cemented with calcium carbonate. Fluvial deposit. 100 to 250 feet thick.

19. Wingate Sandstone: (Upper Triassic) Reddish brown, crossbedded, quartz sandstone. Stands as steep cliffs. Well cemented with calcium carbonate. Strongly stained with manganese oxide (desert varnish). Eolian deposit. 350 to 450 feet thick.

20. Chinle Formation: (Upper Triassic) Divisible into three members, in descending order: 1) the Church Rock Member is a reddish brown to greenish gray sandstone and shaly siltstone; 2) the Moss Back Member (also called the Shinarump Conglomerate) is a grayish conglomeratic sandstone with irregular bedding and abundant petrified and fossil wood in places; and, 3) Temple Mountain Member is a purple and white mottled sandstone. The entire formation was deposited in a fluvial environment. Hosts roll-front type uranium deposits (in the Moss Back Member), and is oil impregnated in places. Forms benches. Up to 400 feet thick.

21. Moenkopi Formation: (Middle to Lower Triassic) The upper part is a reddish brown (locally altered [bleached] to a greenish gray), petroliferous, sandstone and shaly siltstone (slope former). The middle section is the Sinbad Limestone Member that is a yellowish gray, crystalline, locally oolitic limestone with a few siltstone and sandstone interbeds (forms resistant caps and long dip slopes). The lower part is greenish gray to yellowish brown quartz sandstone with interbedded shaly siltstone and mudstone with some thin limestone at the base and occasional gypsum beds (forms gentle slopes). Oil impregnated in places.

The Moenkopi has also been mapped as four different members: the upper Moody Canyon, Torrey, Sinbad Limestone, and lower Black Dragon. Marine deposit. 375 to 935 feet thick.

22. Kaibab Limestone: (Lower Permian) Light brown limestone. Locally sandy and petroliferous. Fossiliferous with chert geodes. Resistant, forms dip slopes. Referred to as the Black Box Dolomite by some. Marine deposit. 40 to 80 feet thick.

23. Cutler Group: (Lower Permian) This diverse group of rocks contains a variety of time equivalent formations that go by different names across the region. Most of these rocks are not exposed as outcrop in the planning area. Overall, the rocks are mostly clastic deposits with an eastern provenance in the Uncompahgre Highlands that were deposited in a variety of sedimentary environments including eolian, fluvial, and shallow marine. Formations include: 1) White Rim Sandstone; 2) De Chelly Sandstone; 3) Organ Rock Shale; 4) Cedar Mesa Sandstone; 5) Halgaito Formation; and, 6) Elephant Canyon Formation. The Elephant Canyon formation is mostly a carbonate deposit, and has also been referred to as the Rico Formation. Both the White Rim and the Cedar Mesa Sandstone have been mapped as the Coconino Sandstone. In some places in southeast Utah, the clastic arkosic facies are identified as undifferentiated Cutler Group. Up to 2,200 feet thick.

24. Hermosa Group: (Pennsylvanian) The Hermosa Group is divided into an upper Honaker Trail Formation, and a lower Paradox Formation. Only a small portion of the Honaker Trail is exposed as outcrop in the planning area on the east side of the San Rafael Swell (Map 12). Overall, the Hermosa Group consists of reddish brown limestone, shale, and limy shale that contain thick sequences of evaporites in the Paradox Formation. Approximately 29 evaporite-black shale cycles have been recognized in the thicker parts of the basin (Stokes, 1986). Each evaporite cycle (containing primarily anhydrite, gypsum, halite, sylvite and potash) can be correlated with an equivalent carbonate cycle on the southwest shelf of the basin near the Four Corners area. Biohermal mounds within these carbonates form petroleum reservoirs outside of the planning area in San Juan County. Shallow marine and terrestrial deposit. Up to 2,400 feet thick.

As shown on Maps 9 and 12, the only intrusive igneous rocks in the planning area are located on the southwest side of the San Rafael Swell. These are small diabase sills and dikes of Tertiary age.

2.2.3 Structural Geology and Tectonics

Overall, the tectonic structure of the planning area is distinguished by four features as follows: 1) the Uinta Basin; 2) the San Rafael Swell; 3) the Paradox Basin; and 4) the

Wasatch Plateau (Hintze, 1988; Stokes, 1986). Map 13 shows the major structural features of Carbon and Emery Counties while regional cross sections are provided in Attachment 2.

As described above in Section 2.1.3, the Uinta Basin was a large lacustrine basin that received sediment from adjacent highlands uplifted during the Laramide orogeny. Accordingly, the basin itself is broadly defined to include those areas covered by Tertiary lake deposits, and includes the Book Cliffs and Roan Plateau in Carbon County in addition to the Uinta Basin proper identified by Stokes (1986) which is located to the north of the planning area (Map 13). Structurally, the Uinta Basin is a large east to west trending asymmetrical syncline whose topographic axis lies approximately 10 to 15 miles south of the structural axis (UGS, 1996). Currently, the center section of the Uinta Basin is still a basin in the topographic sense because surrounding areas (i.e., Uinta Mountains, Wasatch Range and Book/Roan Cliffs) are higher. The southern margin of the Uinta Basin appears as the steep, sinuous escarpments known as the Book Cliffs, which is an erosional, not a structural feature (Cross Section H-G, Attachment 2). High-angle normal faults cut the Cretaceous and Tertiary section of the Uinta Basin, most of which trend about N70^{o}W, with some trending N10^{o}W.

Most of Emery County is occupied by the San Rafael Swell, a broad northeast trending upwarp approximately 75 miles long and 30 miles wide that is part of a much larger, double plunging anticlinal (e.g., dome) structure. Although the swell (the physiographic unit) and the anticline (the structural unit) are commonly viewed as the same feature, they are wholly different in that the anticline is a much larger feature that extends northward under the Mancos Lowlands to the foot of the Book Cliffs (USGS, 1988). Strata on the east side of the anticline dip steeply (45-85^{o}) where resistant units such as the Navajo Sandstone are exposed as hogback ridges. Locally the strata along the east flank are vertical or overturned. On the west side of the structure, rocks dip more gently in the 5 to 15 degree range (Stokes, 1986). The axis of the San Rafael anticline, although sinuous in detail, plunges about N20^{o}E. Near the northern end of the swell, the anticlinal axis bifurcates into an eastern and western branch, but this has little effect on the overall structure of the swell (USGS, 1988). Superimposed on the anticlinal structure are a series of high-angle normal faults, most of which strike northwest or westerly. A few of the faults on the west flank of the swell trend northeast or northerly. Local faulting and folding aside, sedimentary rock strata throughout the planning area generally dip away from the core of the San Rafael Swell. Age relationships suggest that the swell developed during early Tertiary time and deformation continued through the middle Tertiary. Cross section H-G in Attachment 2 shows the geology across the Uinta Basin, Book Cliffs and San Rafael Swell.

The southeast corner of Emery County is considered the northwestern most extension of the Paradox Basin that received sediment throughout much of Pennsylvanian and Early Permian time. Drilling and geophysical data suggests that the northeast margin of the Paradox Basin is a high angle reverse fault adjacent to the Uncompahgre Uplift that involved several thousand feet of vertical displacement from Pennsylvanian through early Triassic time (Hintze, 1988). This "yoked" basin-uplift pattern extended from Utah southeastward into Arkansas forming a paleogeographic feature known as the "Ancestral Rockies." While the western bounding structure of the Paradox Basin is not well defined, the basin itself is defined not by its structure but by the aerial extent of evaporite deposits within the Pennsylvanian Hermosa Group. Overall, the Paradox Basin is oriented northwest to southeast, and includes an area approximately 110 miles wide, and 180 miles long extending from Durango, Colorado, in the southeast to approximately 20 miles northwest of the town of Green River in Emery County (Kelly, 1958; Hintze, 1988). The basin is also informally referred to as the Paradox Fold Belt due to deformation of Permian and Mesozoic strata caused by the movement of salt within the Pennsylvanian Paradox Formation into anticlines (Cross Section L-K, Attachment 2). Fifteen diapiric salt anticlines have been mapped in a southeasterly trend, and are believed to have been localized above older faults that cut pre-salt bedrock (Hintze, 1988). The Paradox Basin contains thick sequences of evaporite deposits within the Paradox Formation that is mined for gypsum, salt and potash; and also hosts significant oil and gas resources. However, most of these economic deposits are southeast of the planning area in Grand County.

The Wasatch Plateau forms the western border of the planning area in Carbon and Emery Counties, and consists of uplifted Mesozoic and Tertiary strata along the gently dipping western flank of the San Rafael Swell. These rocks are broken by a series of en echelon, north trending normal faults and grabens with displacements up to 1,500 feet (Map 13 & Cross Section I-J, Attachment 2). These faults are middle to late Tertiary in age, and are genetically related to regional extension making the Wasatch Plateau transitional between the Colorado Plateau and the Basin and Range Province. Joe's Valley, a long narrow graben structure, lies on the western end of the planning area, while the Gordon Creek Fault Zone forms the eastern most set of normal faults on the Wasatch Plateau. The steep eastern front of the plateau facing Castle Valley is not related to faulting but is an erosional continuation of the Book Cliffs (Stokes, 1986). From Upper Cretaceous to Paleocene time, much of the Wasatch Plateau region was a lacustrine basin in which the Flagstaff Limestone was deposited.

2.2.4 Geophysics and Geochemistry

Extensive geophysical surveying has been performed across the planning area in connection with oil and gas exploration. These studies have been invaluable for identifying deep-seated structures that are not exposed as outcrop. For example, seismic data has identified the eastern bounding structure (high angle reverse fault) of the Paradox Basin. Most of the geophysical work executed in the planning area has been in association with oil and gas exploration. However, the majority of this data remains classified as confidential business information.

2.2.5 Historical Geology

As noted in Section 2.1.5, the Upper Jurassic Morrison Formation is exposed at numerous locations in the planning area, and is world famous for its abundance of dinosaur fossils. Of particular note is the Cleveland-Lloyd quarry site located on the north side of the San Rafael Swell in Emery County in which carnivore species such as Allosaurus outnumber herbivores by 10 to 1 (Stokes, 1986). The collecting of dinosaur fossils is prohibited by Utah State law on all public lands without a special scientific permit. In general, most paleontological resources (including some petrified wood) are subject to additional protective measures on public lands, the conditions of which are typically specified in the EIS.

3. DESCRIPTION OF ENERGY AND MINERAL RESOURCES

This section of the Mineral Potential Report is divided into two parts. Section 3.1 will discuss the presence and occurrence of various energy and mineral resources within the planning area that are of economic significance; while Section 3.2 will discuss history of mineral exploration, prospecting and development. In general, only minerals that are either known to occur or have occurrence potential will be discussed in this report. For example, geothermal energy is not discussed because there are no known thermal areas in Carbon or Emery Counties. Leasable, energy related minerals are discussed first (e.g., coal bed methane, oil/gas and solid hydrocarbons), followed by locatables (e.g., precious/base metals, gypsum and clay) and saleables (sand/gravel, building stone and humate). As described in Section 1.2, while common varieties of clay are salable mineral commodities, specialty clay deposits such as most bentonites are located with claims.

3.1 MINERAL DEPOSITS

3.1.1 Coal

As previously noted, The UGS, BLM, and USGS are currently working on the NCRA project to determine the amount of coal remaining for future development in Carbon and Emery Counties. The BLM has determined that the results of this project will become incorporated into this Mineral Potential Report as soon as they are available. Attachment 4 of this document has been reserved for the inclusion of coal resource and development potential information. However, because a description of coal bearing strata in the planning area provides necessary background information for the assessment of other mineral resources, particularly coal bed methane, a brief discussion of coal occurrence will be included in this section.

The Upper Cretaceous coal deposits in Carbon and Emery Counties are the largest and most extensive in Utah, and are nationally significant as well. The three major coal fields in the planning area are, from north to south, 1) Book Cliffs; 2) Wasatch Plateau; and, 3) Emery (Map 14). The Blackhawk Formation of the Mesaverde Group hosts the Book Cliffs and Wasatch coal fields, while the Emery field is developed in the Ferron Sandstone Member of the Mancos Shale (UGMS, 1979).

Coal is generally classified by rank in accordance with standard specifications of the American Society of Testing and Materials (ASTM) Standard D-388. A brief synopsis of the classification system is presented below. Most of the coals in the planning area are high-volatile bituminous in rank.

1. Anthracite
    a. Meta-anthracite
    b. Anthracite
    c. Semi-anthracite

2. Bituminous
    a. Low volatile bituminous (≥78% but < 86% fixed carbon)
    b. Medium volatile bituminous (≥69% but <78% fixed carbon)
    c. High volatile "A" bituminous (≥31% but <69% fixed carbon
    d. High volatile "B" bituminous (≥13,000 but <14,000 Btu/lb moist)
    e. High volatile "C" bituminous (≥11,000 but <13,000 Btu/lb moist

3. Sub-bituminous
    a. Sub-bituminous "A" (≥11,000 but <13,000 Btu/lb moist)
    b. Sub-bituminous "B" (≥9,500 but <11,000 Btu/lb moist)
    c. Sub-bituminous "C" (≥8,300 but <9,500 Btu/lb moist)

4. Lignite

3.1.1.1 Book Cliffs

The Book Cliffs coal field extends easterly along the Carbon-Duchesne County line from the North Gordon fault zone to the town of Sunnyside, and then sweeps southeasterly to the Green River. The Book Cliff field is continuous with the Sego coal field to the east, and with the Wasatch Plateau field to the west (Map 14). The Book Cliffs field is a northward dipping monocline in which coal is exposed along the high cliffs along the south edge of the Uinta Basin (UGS, 1997). The Book Cliffs themselves form the southern end of the coal field. Although the Blackhawk Formation strikes nearly parallel to the cliff face and dips gently to the north, cover and overburden build up rapidly behind the outcrop face such that a relatively narrow zone is amenable to mining. In addition, the cliff face is irregularly and deeply cut by perpendicular drainages such that the overburden varies drastically between spur and canyon. Overall, the field is approximately 4 to 12 miles wide and 70 miles long; and some six-coal zones containing 14 coal beds have been described (UGMS, 1979). These are, from youngest to oldest: the Upper Sunnyside, Lower Sunnyside, Centennial, Rock Canyon, Fish Creek, Gilson, Castlegate D, Kenilworth, Castlegate C, Castlegate B, Castlegate A (Aberdeen), Sub-seam 1, Sub-seam 2, and Sub-seam 3. Overall, the coal-bearing portion of the Blackhawk Formation is about 700 feet thick, with separation between beds ranging from five feet to approximately 200 feet.

The Blackhawk Formation was deposited on an extensive delta plain in swampy areas along the west margin of the Cretaceous epeiric sea (Stokes, 1986). Stratigraphic relationships suggest an eastward regressing sea during Upper Cretaceous time such that the coal beds to the west are older than those to the east. Individual coal beds are up to 25 feet thick, whereas most mined seams are in the 6 to 13 foot range.

3.1.1.2 Wasatch Plateau

The Wasatch Plateau coal field lies in the northwest portion of the planning area in western Carbon and Emery Counties, but includes portions of eastern Sanpete and Sevier Counties (Map 14). Most of this area is in Manti-La Sal and Fishlake National Forests for which the BLM State Office manages the mineral estate (BLM, 2001). The Wasatch field is approximately 90 miles in length and covers some 1,100 square miles where it varies from 7 to 20 miles in width (UGA, 1991; UGS1997). The east boundary of the field is comprised of steep cliff faces of the Blackhawk Formation where coal beds outcrop. These erosional cliffs are topographically contiguous with the Book Cliffs coal field at its northeast end, and are separated from the Book Cliffs by the North Gordon fault zone. On the west side, the coal field is structurally controlled by the Wasatch monocline where folding and faulting drop the coal bearing zones to unfavorable depths for mining operations (Cross Section I-J, Attachment 2). To the south, the Wasatch is continuous with the Salina Canyon coal field in Sevier County (Map 14). Coal beds eventually become buried by Tertiary volcanics on the southwest extremity of the Salina Canyon field (UGMS, 1979). Within the Wasatch Plateau coal field, strata dip gently to the west/northwest, and are cut by several high angle normal faults that generally trend northward. Numerous canyons cut the cliff face along the eastern margin of the field, and indent the coal outcrops to the west.

On the Wasatch Plateau, the Blackhawk Formation is between 700 and 1,500 feet thick and intertongues with the underlying Star Point Sandstone. Overall, 13 significant coal beds have been identified and named in the Wasatch Plateau coal field. These are, from youngest to oldest (UGS, 1999): Rock Canyon, Gilson, Castlegate D, Castlegate C, Castlegate B, Castlegate A, Gordon, Wattis, Bear Canyon, Blind Canyon, Cottonwood, Axel Anderson, and Acord lakes. Over the past several years, a better understanding of the stratigraphic relationship between the Blackhawk Formation and the Star Point Sandstone have lead to the renaming of several coal beds. For example, the bottom three coal beds were previously considered a single coal bed called the Hiawatha (UGS, 1999). Elsewhere, faulting and the lenticular nature of the coal beds have caused some of them to be misidentified or given several different local names (UGS, 1998). Overall, the most important coal beds in the Blackhawk are towards the base of the section from Acord Lakes through Wattis. The northern portion of the Wasatch Plateau coal field contains more extensive coal deposits as compared to areas further south, and the area currently provides about 85 to 90 percent of the state’s coal (UGS, 1998). Along strike in a north to south direction, coal beds are not continuous, and there are areas in the central and extreme southern part of the field that have only thin, discontinuous coal seams (UGMS, 1979).

3.1.1.3 Emery / Ferron

The Emery coal field (also called the Castle Valley field) is parallel to, and about 10 miles east of the southern half of the Wasatch Plateau field in Emery and Sevier

Counties (Map 14). The field is about 35 miles in length and averages six miles wide (UGS, 1997). The principal coal beds occur in the southwest margin of the field in the upper portion of the Ferron Sandstone Member of the Mancos Shale outcropping along a series of low ridges that dip gently to the west/northwest. To the north, coal beds thin and disappear from outcrop; however, drilling data indicates that "significant" coal beds are present within the Ferron Sandstone at depths between 1,000 and 2,500 feet in the northern Castle Valley near the town of Price (UGA, 1991). This area has been referred to as the North Emery coal field (or Ferron Field), although no coal has ever been produced here. The North Emery coal field extends from the vicinity of Ferron, Utah, in the south, to just north of Price in the north. On the east, the North Emery field is defined by the outcrop belt of the Ferron Sandstone (which trends northeast up the Castle Valley), and extends west about 10 miles in what has been termed the "Ferron Fairway" for coal bed methane production (BLM, 1997; UGS, 1995). The Emery coal field terminates in the south where it is buried under thick piles of Tertiary volcanics. As described above, there have been several different names applied to various portions of the Emery and North Emery coal fields. Overall, the two fields combined have also been referred to as the Ferron coal trend.

In general, the coal-bearing portion of the Ferron Sandstone lies in the top portion of the section reported to be up to 750 feet thick near its type location in Ferron, Utah, although no type section has been designated (see stratigraphic section 64, Attachment 1). Up to 13 separate coal beds have been identified and given letter designations A through M in ascending order (UGMS, 1979). Individual coal beds are up to 13 feet thick, and are typically lenticular in form and discontinuous laterally along strike. As described in Section 3.1.12, most of the humate currently mined in Utah comes from weathered coals in the G bed of the Ferron Sandstone. The Emery field has not produced any coal since 1992 (UDNR, 2000).

3.1.2 Coal Bed Methane

The presence of methane gas in coal seams has long been recognized due to explosions and outbursts associated with underground coal mining operations. Only recently, however, has coal been recognized as both a reservoir rock and a source rock for this enormous "unconventional" energy resource.

During the coalification process that accompanies burial, organic matter is converted into coal; and methane gas is produced along with water, carbon dioxide, nitrogen and heavier hydrocarbon fractions (USGS, 2000). A portion of this methane becomes trapped as the coal seam is compacted, and this can later be extracted as an energy resource. In general, the higher the rank of the coal, the more methane gas is generated and potentially trapped in the coal.

A coal seam is a dual porosity medium that consists of a solid matrix containing micropores, and a fracture system known as cleats (BLM, 1997). In the primary type of storage, methane molecules are adsorbed as a single layer to the walls of the micropores. The internal surface area is very large, and can exceed 1 billion square feet per ton of coal (BLM, 1992). This results in a large storage capacity for methane that can exceed that of conventional gas reservoirs by a factor of 3 to 7 (BLM, 1997). Methane gas is also stored in a free state (or dissolved in groundwater) within the cleat fractures of the coal, but this amount is small as compared to the adsorbed gas.

Although primary permeability is essentially nonexistent in coal beds, they commonly serve as aquifers as their fracture and cleat systems are well developed and are generally fully saturated prior to coal bed methane (CBM) production (USGS, 1995). CBM is extracted by pumping water out of the coal thereby lowering the hydrostatic pressure and causing methane to desorb from the coal and travel to the extraction well via the coal cleat system. Initially, large amounts of water are produced before methane gas can desorb and begin to flow towards the well bore. As methane production from the well increases over time, water production decreases. Eventually, gas production declines as groundwater production diminishes in the last stages of a well's production. CBM wells are typically vertical bores due to the physical constraints of the downhole groundwater pumping equipment that limits deployment in cased holes with short to medium radius curves.

CBM is an attractive resource because much of the nation's coal deposits are already known, and lie at relatively shallow depths making it relatively easy and inexpensive to drill wells. CBM accumulations also tend to be widespread and laterally extensive across basins where coal beds are present in the stratigraphic section. Accordingly, locating CBM wells to target a producing horizon is somewhat easier than for a conventional gas well that is dependent on a trap. In addition, CBM production does not preclude the future mining of the coal reservoir through traditional underground methods; but appears to actually benefit future mining operations by first removing the methane which poses a health and safety hazard, and is a contributor to greenhouse emissions (USGS, 2000). The main concern with CBM wells is gas recoverability constrained primarily by costs and technology.

Despite its many advantages, CBM production poses some significant environmental issues, most notably the production of large volumes of wastewater, particularly in the early stages of well development. While water produced from CBM wells can be potable, it is frequently saline to hypersaline, and may contain total dissolved solids (TDS) at concentrations up to 170,000 mg/L (USGS, 2000a). Wastewater produced from CBM wells can also have high concentrations of dissolved organic constituents and metals. Overall, CBM water must be disposed of or used for beneficial purposes.

Regardless of the fate of CBM water, some form of treatment is often required prior to disposal or use. Disposal methods include surface discharge, injection to formations below the reservoir rock, or evaporation (or freezing); while common uses include stock ponds, irrigation, artificial wetlands or water supplies.

3.1.2.1 Reservoirs

The coal beds within the Blackhawk Formation and the Ferron Sandstone Member of the Mancos Shale serve as both source rock and reservoir for CBM wells in the planning area. In general, areas of CBM accumulation and production mirror the footprint of the region's coal fields as discussed in Section 3.1.1 (Map 14). That is, CBM areas associated with the Blackhawk Formation are on the Book Cliffs and Wasatch Plateau regions, whereas CBM accumulations associated with the Ferron Sandstone are primarily in the Castle Valley. Because each coal bearing rock unit has multiple coal seams over its thickness, individual CBM wells may be open to the formation at multiple depth intervals, or there may be separate wells targeting specific depths and seams. In general, CBM accumulations dissipate within coal seams adjacent to mined out areas or outcrops due to desorption of the gas to the atmosphere (UGS, 2001).

As part of their 1995 oil and gas resource assessment, the USGS divided the country into 8 Regions containing 72 Provinces and hundreds of "plays" (USGS, 1995). A play was defined as a "set of known or postulated oil and/or gas accumulations sharing similar geologic, geographic, and temporal properties such as source rock, migration pathways, timing, trapping mechanism, and hydrocarbon type." Play's are further grouped into two broad categories: 1) conventional accumulations which are discrete deposits typically bounded by a down-dip water contact; and, 2) unconventional accumulations such as gas shales and CBM deposits which tend to be more continuous in nature. Within the planning area, the USGS has identified two CBM plays in what is referred to as the Uinta-Piceance Basin Province (Province 20): 1) the Book Cliff CBM Play (Play 2050); and, 2) the Emery CBM Play (Play 2052). The USGS is currently in the process of refining the extent and character of these plays as more information becomes available. For example, CBM is currently being produced from areas that are outside the boundaries of both the Book Cliffs and Emery Plays in areas east of the Castle Valley town sites, and in areas north of Price. The boundaries of these CBM plays as defined in the 1995 assessment are shown on Map 15; however, the boundaries are in a state of change. For example, the Emery Play is now considered to extend north to the base of the Book Cliffs rather than to the vicinity of Price as shown on Map 15. Similarly, the northern edge of the Book Cliffs Play now extends downdip into areas of approximately 5,000 feet of overburden.

As is the case with their associated coal field names, different CBM areas have been referred to by different names by different groups, and their boundaries are not rigorously defined. For example, the USGS Emery Play is referred to by the UGS as the Ferron Sandstone Play, and is also informally called the Ferron Fairway, or simply the Ferron Trend. The Book Cliffs Play (USGS usage) is also called the Blackhawk Play (UGS usage).

Within each CBM play, individual fields have been identified; however, this nomenclature is not necessarily accurate in the context of CBM deposits relatively continuous in nature and not related to a single structural or stratigraphic feature as is a conventional gas field. In practice, areas that have traditionally been referred to as CBM fields within the planning area are typically permit or lease areas of the companies proposing the development project. Nevertheless, several CBM fields have been defined within the planning area, the boundaries of which have been revised numerous times over the years as development of these areas has progressed. These include the Helper/Price, Drunkards Wash/Price, and Buzzard Bench/Ferron fields covering most of the Emery Play or Ferron Fairway in Carbon and Emery Counties. In the Book Cliffs Play, the only CBM field that is commonly named is the Castlegate/Matt's Summit. These CBM fields and plays are shown on Map 16. CBM fields have not yet been developed on the Wasatch Plateau.

In the Book Cliffs, the total coal isopach of the Blackhawk Formation is up to 68 feet (with a mean of 20 feet at any one location) indicating significant potential for the region to become a major source of gas (USGS, 1995). In the Emery Play, the resultant coal isopach is up to 40 feet in places, with numerous areas exceeding 20 feet (UGS, 1995).

3.1.3 Oil and Gas

This section of the Mineral Potential Report discusses oil and gas accumulations within the planning area that are not associated with coal beds (e.g., CBM as discussed in Section 3.1.2) or solid hydrocarbons such as oil/tar sands, oil shale, and gilsonite (see Section 3.1.4). This includes both conventional and unconventional deposits of liquid petroleum oil, and natural gas of all types including methane, carbon dioxide and inert gases such as helium. Conventional accumulations are defined as discrete deposits, usually bounded by a down-dip water contact, from which oil and gas can be extracted using traditional development practices. Traditional development practices include: 1) production at the surface from a well as a consequence of natural pressure within the reservoir; 2) artificial lifting from the reservoir to the surface; and, 3) the maintenance of reservoir pressure by means of water or gas injection (USGS, 1995). Unconventional accumulations are a broad class of hydrocarbon deposits, of primarily continuous type (i.e., pervasive throughout a large area), that cannot be recovered using traditional development practices. These include gas in "tight" sandstones and gas shales, but also include CBM deposits as previously discussed in Section 3.1.2.

In their 1995 assessment of oil and gas resources, the USGS defined two provinces that together encompass the entire planning area. These are the Uinta-Piceance Basin (Province 20), and the Paradox Basin (Province 21), which together are part of Region 3 (Colorado Plateau and Basin and Range) (USGS, 1995). Each province is in turn divided into a number of different plays defined as a known or postulated oil and/or gas accumulations sharing similar geologic, geographic, and temporal properties such as source rock, migration pathways, timing, trapping mechanisms, or hydrocarbon type (USGS, 1995). Because each play is defined by a variety of different parameters, many of them overlap each other in geographic boundaries. The USGS oil and gas plays that are defined within the planning area are shown on Map 17, and are identified below in Table 5 (UGS, 2002b; USGS, 1995).

Table 5. USGS Oil and Gas Plays in Carbon and Emery Counties.

Play Name	Play No.	Comments
Uinta-Piceance Basin Province (20)		
Uinta Tertiary Oil and Gas	2002	Conventional play. Mostly stratigraphic traps in the sandstones of the Colton/Wasatch and Green River Formation. Source is both Tertiary and Upper Cretaceous rocks. Currently productive in the planning area for gas and some oil. Northeast Carbon County
Upper Cretaceous Conventional	2003	Conventional play. Both reservoir and source rocks are primarily the Upper Cretaceous Mesaverde Group. Traps are structural and stratigraphic. Includes most of Carbon County. Currently productive for gas in the planning area. Only moderately explored in Utah.
Cretaceous Dakota to Jurassic	2004	Conventional play. Reservoir rocks include the Dakota and Entrada Sandstones, and the Morrison Formation. Mostly structural traps. Currently productive in the planning area for oil and gas. Major structures explored or developed, but opportunity exists to find subtler traps with the play.
Permian – Pennsylvanian Sandstones and Carbonates	2005	Conventional play. Both structural and stratigraphic traps occur in sandstone and carbonate rocks of primarily Permian age. North Carbon County. Not currently productive in the planning area. High degree of uncertainty for finding undiscovered hydrocarbon accumulations due to poor understanding of source and migration pathway.
Tight Gas Uinta Tertiary West	2016	Unconventional, continuous play. Stratigraphic and diagenetic traps in Tertiary sandstone facies with a source in the underlying Mesaverde Group. Northeast corner of Carbon County. Currently productive in planning area for gas and some oil. Play is only sparsely tested, and untested cells are estimated to only have a 0.3 success ration of producers to wells drilled.
Basin Flank Uinta Mesaverde	2018	Unconventional, continuous play. Reservoir rocks are Tertiary sandstones with a carbon source in the Mesaverde Group. Grades updip into Play 2003. Mostly unexplored. Northeast Carbon County. Currently productive in the planning area for gas. Play is sparsely tested, and untested cells are estimated to have a 0.6 success ratio of producers to wells drilled.
Paradox Basin Province (21)		
Fractured Interbed	2103	Unconventional, continuous play (hypothetical). Reservoir and source is primarily the Paradox Formation. Structural and stratigraphic traps as a result of fractured shales. Southeast Emery County.

Table 5. USGS Oil and Gas Plays in Carbon and Emery Counties.

Play Name	Play No.	Comments
Salt Anticline Flank	2105	Conventional play. Structural and stratigraphic traps along the axis of the northwest flank of the Paradox salt basin. Reservoir and source is primarily in the Hermosa Group, but also in the Cutler Group. Southeast Emery County. Currently productive for gas outside the planning area. Drilling has only sparsely tested the play area.
Permo-Triassic Unconformity	2106	Conventional play. Reservoir rocks include the Moenkopi Formation, Kaibab Limestone and sandstones within the Cutler Group (Coconino and White Rim). Play is very large because source rocks, hence migration pathways, are unknown. Although not shown on Map 17, this USGS play could include the Grassy Trail field on the northeast side of the San Rafael Swell which is currently productive for oil.
Cretaceous Sandstone	2107	Conventional play. This is an extension of Play 2003. The major producer has been the Ferron Sandstone on the Wasatch Plateau. Source rock is Mancos Shale and Mesaverde Group. Predominately structural traps. Western Emery County. Currently productive for gas. Most major structures have been drilled, but may have untapped compartments hosting undiscovered gas accumulations.

Notes:

- CBM plays (e.g., Book Cliffs [2050] and Emery [2052]) are excluded from this table.
- USGS oil and gas plays are shown on Map 17.

Within each oil and gas play, there are a number of fields that are individual producing units consisting of a single pool or multiple pools of hydrocarbons related to a single structural or stratigraphic feature (USGS, 1995). Specific oil and gas fields within the planning area are discussed in Section 3.2.3.

While shows of oil and gas can be found in numerous areas, significant accumulations are found only where an adequate organic rich source rock is available possessing a favorable thermal maturation history, porous and permeable reservoir rock is present, and the accumulations are contained from escape by either a structural or stratigraphic trap. Oil and gas deposits within the planning area are found in a variety of rock types from Paleozoic to Tertiary age, and are contained by both structural and stratigraphic traps. Rock units that serve as host reservoirs in the planning area include, from youngest to oldest: Green River, Colton/Wasatch, Price River, Ferron, Dakota, Cedar Mountain, Entrada, Navajo, Moenkopi, Kaibab, Cutler, and Hermosa (USGS, 1995; UGA, 1990). Source rocks are typically organic rich siltstones, black shales, calcareous mudstones and coals that are found within the Green River, Colton/Wasatch, Blackhawk, Mancos Shale, Carmel, Moenkopi, Cutler and Hermosa. Historically, most of the hydrocarbons produced in Carbon and Emery Counties have come from reservoirs hosted by the Cretaceous Ferron Sandstone Member of the Mancos Shale, the Triassic Moenkopi Formation, and the Tertiary Green River and Wasatch Formations (UGS, 2002a).

3.1.4 Solid Hydrocarbons

The Uinta Basin contains the largest accumulation of solid hydrocarbons in the United States, and significant deposits are also found in the Triassic rocks of the San Rafael Swell (USGS, 1995). For the purposes of this report, solid hydrocarbons include tar sands (also referred to as bituminous sandstones, oil sands, or oil impregnated rock), oil shale, and a variety of naturally occurring asphaltic substances such as gilsonite, ozokerite, and wurtzilite. Within the planning area of Carbon and Emery Counties, tar sand accumulations are the most wide spread solid hydrocarbon deposit type, and have the most potential economic significance. Oil shales are locally wide spread in the northeast corner of Carbon County, while the "mineral like" asphaltic substances occur mostly towards the central portion of the Uinta Basin in Uintah and Duchesne Counties. Although gilsonite, ozokerite, and wurtzilite do occur in association with tar sand and oil shale deposits in the planning area, they are a minor association, and are not present in economic quantities by themselves. Accordingly, their presence will not be discussed in this Mineral Potential Report.

3.1.4.1 Tar Sands

Tar sands are loosely defined as any sedimentary rock impregnated with heavy, viscous crude oil that cannot be recovered by conventional techniques, but rather requires an external energy source (i.e., heat) to mobilize the oil (UGS, 1996). Tar sand deposits need not have a sandy host, and other porous rocks such as fractured siltstones and carbonates have been classified as tar sands in the Uinta Basin. In 1980, the U.S. Department of Energy defined tar sands as any consolidated or unconsolidated rock (excluding coal, oil shale and gilsonite) that contains hydrocarbons (bitumen), and has a gas-free viscosity greater than 10 pascal seconds at the original reservoir temperature. Following the passage of the 1981 Federal Combined Hydrocarbon Leasing Act, the BLM added the phrase "or is produced by mining or quarrying" to the definition of tar sands (43 CFR 3140).

Most tar sand deposits in Utah probably formed from crude oil that accumulated in conventional petroleum reservoirs near the land surface. During Laramide uplift, these reservoirs were subsequently breached by erosion cutting through the reservoir cap rocks thereby allowing the volatile components of the oil to escape to the atmosphere (UGS, 1996). In addition, microbes contained within meteoric groundwaters preferentially metabolize the lighter hydrocarbon fractions that also served to demobilize the oil, and increase its viscosity.

Within the planning area, tar sand accumulations are found in the Tertiary Wasatch/Colton and Green River Formations of the Uinta Basin, and in the Mesozoic rocks of the San Rafael Swell region (UGMS, 1983). In general, tar sands occur in five separate areas in Carbon and Emery Counties (Map 18):

1. South Flank of the Uinta Basin: Including the Sunnyside, Cottonwood-Jacks Canyon, and Minnie Maud Creek deposits. Hosted by the Green River and Colton Formations.

2. North Part of the San Rafael Swell: Including the Red Canyon, Black Dragon, Wickiup, and Cottonwood draw deposits. Hosted by various members of the Chinle and Moenkopi Formations.

3. South Part of the San Rafael Swell: Including the Justensen Flats, Family Butte, Flat Top, Chute Canyon, Temple Mountain and San Rafael Swell Deposits. Hosted by various members of the Chinle and Moenkopi Formations, with lesser occurrences in the Navajo Sandstone and Kayenta Formation (Justensen Flat).

4. Nequoia Arch: Including unnamed, minor occurrences in southwest Emery County. Hosted by the White Rim Sandstone.

5. Sweetwater Dome: Minor occurrence in southeast Emery County. Hosted by the Curtis Formation.

The Tertiary accumulations in the Uinta Basin of northeast Carbon County are by far the most significant, and include the giant Sunnyside deposit along with the adjacent Cottonwood-Jacks Canyon area, and the smaller Minnie Maud and Nine Mile Canyon areas to the north along the Carbon/Duchesne County line (Map 18). The Cottonwood-Jacks Canyon area is the direct downdip extension of the Sunnyside deposit where the bitumen bearing rock strata are buried under more overburden, are thinner, less saturated, and more discontinuous in extent (USGS, 1990).

Within the Sunnyside deposit, bitumen saturated sandstone bodies occur within the lower (marginal lacustrine facies) sections of the Green River Formation (Garden Gulch and Douglas Creek Members), and in the upper sections of the Wasatch/Colton Formation (UGS, 1996). These rocks were deposited in high sinuosity streams along the south margin of Lake Uinta. Porosities of these rocks average 25 to 30 percent, and can contain over 10 percent of bitumen by weight (USGS, 1990). Up to 32 saturated beds have been mapped within Sunnyside, and usually only three to 12 principle pay zones are present (UGS, 2002a). At Minnie Maud and Nine Mile Canyon, tar sand accumulations are in the middle section of the Green River Formation (Parachute Creek and Garden Gulch Members), and in the upper Wasatch/Colton.

To the south in Emery County, tar sands are exposed at the surface and present at shallow depths in the central portion of the San Rafael Swell where Triassic rocks outcrop (Maps 18 and 9). Host rocks for tar sand accumulations include the Black Dragon Member of the Moenkopi Formation, and the Moss Back (Shinarump Conglomerate) and Temple Mountain Members of the Chinle Formation (USGS, 1988a, 1990). These tar sand accumulations are much smaller, less continuous, and generally contain more sulfur (2% to 4%) as compared to those in the Uinta Basin. The minor tar sand occurrences in the Nequoia Arch and Sweetwater Dome are primarily hosted by the White Rim Sandstone, and the Curtis Formation, respectively.

3.1.4.2 Oil Shale

Oil shales occur throughout the northeast corner of Carbon County within the Green River Formation, and are typically a dark brownish-bluish gray, very fine grain, thin-bedded shale (USGS, 1990). Throughout the middle section of Green River Formation where oil shales are present, they are typically interbedded with marlstone and siltstone (USGS, 1990). Although the fissility of oil shale is similar to ordinary shale, it has much less mineral matter and is softer. Oil shale has a high content of kerogen that formed from the compacted residue of microorganisms that lived in Eocene Lake Uinta. Accordingly, the source rock and reservoir rock are typically one-in the-same in oil shales as compared to tar sands in which the bitumen has been mobilized. As with tar sands, the kerogen from oil shales is generally extracted by heating the material, a process called retorting.

Within the planning area, oil shale beds are both thinner and less abundant than those east of the Green River in Uintah County where they have been studied in far greater detail. In Uintah County, this includes lands that were previously designated Naval Oil Shale Reserve #2 by the U.S. Congress, a small portion of which extended west of the Green River onto the West Tavaputs Plateau in Carbon County. In the eastern Uinta Basin, oil shales with the highest concentration of kerogen occur primarily in what is know as the Mahogany ledge zone in the Parachute Creek Member (or the base of the Upper Member [Tgu] as defined by the USGS [1990]) of the Green River Formation (UGMS, 1980; USGS, 1969). The Mahogany ledge varies from 15 to 150 feet in total thickness; however, the cumulative thickness of discrete, highly concentrated, oil shale beds typically do not exceed 6 feet (USGS, 1990). Within the planning area, the Green River Formation contains many thin oil shale beds both within and above the Mahogany ledge, and to a lesser degree below the ledge. Map 18 shows areas in Carbon County where oil shale deposits of the Mahogany ledge are present in the shallow subsurface (typically 2,000 feet or less). As shown on Map 18, this area forms a triangular shaped region, but only the northeastern most corner of Carbon County can be considered a significant resource because oil shale thickness and kerogen content decrease towards the southwest. This division has traditionally been drawn along the 15-gallon/ton saturation line (USGS, 1969).

3.1.5 Uranium and Vanadium

Although trace levels of uranium occur in rocks of nearly every age and type, the Salt Wash Member of the Jurassic Morrison Formation, and the Moss Back Member of the Triassic Chinle Formation account for nearly all of the historic Utah production. Within the planning area, these rocks are exposed around the San Rafael Swell in south-central Emery County (Map 12).

Sandstone hosted epigenetic ore deposits are the dominant type of uranium occurrence in the planning area where mineralization is strongly controlled by the texture and architecture of the fluvial channel deposits. Ore bodies can assume a variety of morphologies, but the most common form is called a roll front in which the uranium enriched "roll" is stratabound, and displays an irregular "C" shape in cross section that is elongate in plan view along a direction parallel to the paleocurrent direction of the channel (Galloway and Hobday, 1983). In most epigenetic deposits, uranium is leached from low-grade source rocks and transported to the site of accumulation by oxidizing surface and groundwaters, and then precipitated from solution when reducing conditions are encountered. Consequently, uranium mineralization is a post depositional, low temperature phenomenon that is controlled by the Eh/pH conditions of the hydrologic system. Both the Salt Wash and Moss Back Members were deposited in an aggrading fluvial environment characterized by multiple channels with low sinuosity (i.e., braided), and a high frequency of avulsion (Galloway and Hobday, 1983). Within point bar and crevasse splay channel sequences, reducing conditions were typically accompanied by the presence of carbonaceous layers, lignite, asphaltite, or woody debris that can become partially replaced by uranium minerals (UGMS, 1978). Around the San Rafael Swell, uranium mineralization hosted by the Moss Back Member of the Chinle Formation is also commonly associated with tar sand deposits (see Section 3.1.4.1).

In addition to roll front type deposits, uranium mineralization in the planning area also occurs in veins that may have been introduced from hydrothermal activity associated with breccia pipes and collapse structures (USGS, 1988a, 1990a). However, some of these structures may also have formed in a manner similar to sinkholes, but they appear to be affected by roll front uranium deposition as well. Throughout the San Rafael Swell region, the Salt Wash Member averages 218 feet thick, while the Moss Back member is about 100 feet thick (UGMS, 1978).

While fluvial channel, point bar and crevasse splay sequences are the dominant uranium hosts in both the Salt Wash and Moss Back Members, coarse grain facies (i.e., containing gravels and cobbles) are less likely to support proper reducing conditions for a roll front deposit to form. This, in part, explains why the Moss Back Member provides the dominant uranium host in Emery County because it represents a more distal channel sequence deposited by Upper Triassic streams flowing in a northwest direction from highlands in Colorado and New Mexico (Hintze, 1988; USGS, 1990a). Further to the southeast in San Juan County, the Salt Wash Member becomes the dominant uranium host where it becomes finer grained and more distal from its source.

Uranium is the heaviest naturally occurring element, and ore deposits can host a variety of other low temperature metals and rare earth elements that have been extracted in association with uranium. Chief among these are vanadium, radium and copper; but ores of cobalt, zinc, iron, fluorine, arsenic, cesium, cadmium, potassium, selenium, and thorium have also been produced in very small quantities (USGS, 1969, 1990a). Within the planning area, copper has only been produced as a by-product associated with the mining of other metals, principally uranium. Overall, the mineralogy of a sedimentary uranium deposit can be very complex, and may include the following unoxidized minerals: uraninite, coffinite, pyrite, sphalerite, tetrahedrite-tennanite, chalcocite, galena, chalcopyrite, bornite, marcasite, molybdenite, and montroseite. Oxidized mineral forms may include: carnotite, autunite, tyuyamunite, meta-zeunerite, pascoite, corvusite, malachite, and azurite (USGS, 1990a).

3.1.6 Precious and Base Metals

Due in part to the lack of igneous or hydrothermal activity, there are very few metal deposits in the planning area other than those associated with low temperature radioactive mineral occurrences in Emery County. This includes both precious metals (primarily silver and gold), and base metals (copper, manganese, lead, zinc, iron, etc.). Minor occurrences of manganese, silver and copper are know from Jurassic and Cretaceous strata in Emery County, and small amounts of placer gold have been discovered in unconsolidated Quaternary sediments. Overall, only very minor production of metallic minerals has occurred in the planning area; and metal deposits (other than radioactive occurrences) whether they are placer, disseminated or lode, are minor and relatively unimportant in Carbon and Emery Counties.

As noted in Section 3.1.5, a wide variety of metallic elements are sometimes associated with sedimentary uranium-vanadium deposits, and some of these metals have been extracted during the mining of the radioactive ore. Gold however, has not been demonstrated to occur in association with uranium (U.S. Bureau of Mines, 1989a). While precious metal prospects are numerous in the San Rafael Swell area, little production has occurred other than by-product extraction (Hintze, 1988; USGS, 1969, 1990a). Although uranium mineralization is often restricted to the Salt Wash Member of the Morrison Formation and the Moss Back Member of the Chinle Formation, prospecting for precious metals has also occurred in adjacent strata from Upper Cretaceous to Lower Triassic in age, particularly where they are cut by faults that can transport mineralizing fluids. Overall however, most of the metallic mineralization appears to have occurred post-depositional and at low temperature (USGS, 1969).

In general, no well-documented occurrences of gold are known in the planning area (UGS, 2002a). Prospecting for precious metals, particularly gold, has occurred in unconsolidated Quaternary placer deposits. These include alluvium along the banks of rivers (primarily the Green) and creeks, and in the pediments derived from adjacent uplands such as the Book Cliffs and Wasatch Plateau. Paleochannel deposits have also been prospected, but most of this activity is associated with post depositional mineralization such as roll fronts (see Section 3.1.5), and not with primary detrital sedimentation characteristic of a placer. Rumors persist regarding the presence of fine-grained disseminated gold in the Mancos Shale, and several operators have applied for mine permits for the bulk testing of this material (UGS, 2002a). However, there has been no indication that the Mancos Shale is host to economic concentrations of gold (UGMS, 1999a; UGS, 2002a).

Small occurrences of copper (with associated silver) are known from Emery County not associated with radioactive deposits. These consist mostly of azurite, malachite, and minor chalcocite deposited along bedding planes, fractures and fault zones in Triassic and Jurassic sandstone deposits (e.g., Navajo, Kayenta, Wingate, and Entrada). Most of the copper mineralized faults trend from N60°W to N70°E, but mineralization rarely extends much beyond the fault or fracture (UGS, 2002a).

Small, sedimentary-hosted manganese deposits are known in Emery County that occur in: 1) limey sandstones and shales of the Jurassic Summerville formation; 2) sandy shales, sandstones and conglomerates of the Brushy Basin Member of the Jurassic Morrison Formation; 3) limestone and conglomerate of the Cretaceous Cedar Mountain Formation; and, 4) Recent gravels (UGS, 2002a).

3.1.7 Gypsum

Gypsum, including anhydrite and alabaster, is formed by the evaporation of seawater and precipitation of calcium sulfate. Although gypsum has been mined in Emery County for nearly a century, production in the planning area is relatively small as compared to that obtained from the diapiric intrusions of the Arapien Shale in Sanpete and Sevier Counties (USGS, 1969). Most of Utah's gypsum is processed into wallboard at plants located near Sigurd in Sevier County. However, several operators supply raw gypsum to cement companies where it is used as an additive to retard the setting time, and to the agricultural industry for use as a soil amendment (UDOGM, 2002). The Pennsylvanian Paradox Formation in southeast Emery County also contains gypsum, but its great depth of burial beneath Permian and Lower Mesozoic strata prohibits development considerations. There are no gypsum bearing rocks of any significance in Carbon County.

Within the planning area, gypsum occurs primarily in the upper unit of the Carmel Formation where it is interbedded with reddish brown shaly siltstone; and to a lesser degree as thin interbeds within the upper siltstones of the Summerville Formation (USGS, 1998). Both of these Middle Jurassic units were deposited in tidal flat environments, and outcrop primarily along the west flank of the San Rafael Swell beginning about 10 miles west of Castle Dale, extending southward into Wayne County. As shown on Map 12, the Carmel and Summerville Formations are exposed to a lesser extent on the east side of the swell where gypsum beds tend to be less continuous (UGMS, 1980; USGS, 1969) and dip at a steeper angle. Some of the Carmel and Summerville gypsum beds are strongly folded, compact and fine grained, characteristics that decrease the value of the gypsum for plaster or wall board manufacture. Overall, minable resource grade gypsum beds within the Summerville and Carmel Formations range from 3 to 30 feet in thickness (USGS, 1969).

Extensive gypsum deposits are also contained within the evaporite sequences of the Pennsylvanian Paradox Formation underlying the southeast corner of Emery County. However, these deposits are relatively inaccessible due to their great burial depth under Permian and Triassic overburden. The Triassic Moenkopi Formation also hosts thin, discontinuous gypsum beds in Emery County; however, they are unsuitable for mining purposes as compared to other areas in Utah (USGS, 1969). Localized beds, lenses and nodules of gypsum also occur in the Morrison and Curtis Formations, but these are insignificant from an economic perspective as well (USGS, 1990a).

3.1.8 Potash and Salt

Saline deposits are loosely defined to include all mineral salts which have precipitated from waters of either marine or continental origin through the process of evaporation (USGS, 1969). While this definition includes materials such as gypsum, anhydrite, and some limestone, these commodities are wholly different in their end use, and are typically excluded from discussion of saline evaporites. Saline potassium minerals such as sylvite and carnallite are often referred to as "potash," while the most common salt mineral is sodium chloride or halite. Other valuable salts include potassium sulfate, sodium carbonate, sodium sulfate; and salts of magnesium, lithium, bromine, and boron (UGMS, 1987). Saline deposits are widespread in Utah in rocks and soils from Pennsylvanian to Recent age.

As described in Section 2.2.2, the rocks of the Pennsylvanian Paradox Formation contain approximately 29 distinct evaporite cycles, each containing deposits of halite, sylvite, and a variety of less common saline minerals (Stokes, 1986). The majority of these deposits accumulated in the deepest part of the Paradox Basin currently located to the east of the planning area in Grand and San Juan Counties. However, the Paradox Basin, which has traditionally been defined by the aerial extent of major salt deposition, extends into southeast Emery County where the thickness of saline facies exceeds 3,000 feet in places (Stokes, 1986, UGMS, 1987). The extent of potash and salt deposition in the planning area, along with an isopach map of the saline facies, is shown on Map 19 (Hite and others, 1972; Woodward Clyde, 1983). However, these deposits are buried beneath several thousand feet of Permian and Mesozoic overburden in southeastern Emery County.

3.1.9 Clay

Clay minerals (hydrous aluminum silicates) are relatively common in Utah and are produced by either sedimentary processes or hydrothermal alteration of volcanic rocks (UGMS, 1987). Clay minerals are typically composed of very fine grain, clay size particles (< 4 micros in diameter), thus clay is a term that describes both a group of similar mineral species, and the size of a sedimentary particle. Sedimentary clay can be of either primary depositional origin (i.e., shales and mud rocks), or can be produced by in-situ chemical weathering processes. Clays that are of economic significance that are found in Utah include bentonite, halloysite, kaolinite, montmorillonite, illite, pyrophyllite, smectite, bloating clays, common clay, fire clay, and fullers earth (UGMS, 1987). Common clay is a generic term or industrial classification describing any clay type suitable for firing or making construction brick/tile, or sufficiently plastic to permit molding. Common clay is typically composed of the minerals illite, smectite, and kaolinite. Bentonite is composed predominantly of the mineral montmorillonite.

Although clay deposits can be found throughout the state, most of the commercial production comes from the vicinity of Great Salt Lake, and from mines located in Sevier, Piute, and Garfield Counties. Most of this material is made of clays deposited during the desiccation of Pleistocene Lake Bonneville, or from the in-situ alteration of volcanic ash and rocks (USGS, 1969). Within the planning area, most of the clay deposits consist of bentonite from volcanic ash fall, or common clay of sedimentary origin.

While Carbon and Emery Counties contain potentially large amounts of bentonite interbedded throughout the Mesozoic section, this material is of uncertain quality and little information is available to assess it as a potential resource (UGS, 2002a). Most of the published literature on bentonite deposits discusses this material in terms of stratigraphic markers for correlation purposes, or they examine the geochemistry and alteration patterns of lacustrine bentonite. Nevertheless, four bentonite beds are present in the lower part of the Mancos Shale which can be traced over large portions of the western United States. In addition, bentonitic mudstone is present within the Mussentuchit Member of the Cedar Mountain Formation along the northern and western flanks of the San Rafael Swell. Bentonite layers are also present in the Jurassic Morrison Formation (Brushy Basin Member), and to a lesser degree, in the Carmel Formation and the Chinle Formation (UGS, 2002a). The sources of the bentonite deposits are probably the Tertiary volcanics that are extensively exposed to the west (i.e., up wind) in Sevier, Piute, and Garfield Counties.

While sedimentary clays in the planning area can be found in places throughout the Mesozoic and Cenozoic rock section, they are prevalent in the Mancos Shale, Dakota Sandstone, and the Moenkopi Formation (BLM, 2002; USGS, 1969). Very little information is available on the common clay resources in the planning area.

Clays are used for a variety of commercial and industrial purposes including brick production, drilling and quarrying mud, sealants, liquid dyes, paints, china and ceramics, absorbents, molecular sieves, fillers for paper and rubber production, binders for foundry molds, cosmetics, and medicines. The end use of the clay is determined by its physical properties and its purity. Physical properties that determine clay usage include plasticity, bonding strength, color, vitrification range, deformation with drying and heating, gelation, crystal structure and size, viscosity, and swelling capacity (USGS, 1969). For most uses, the value of a particular clay deposit will depend on the purity of the clay mineral present. Bentonite use is largely dependent on its swelling capacity. High-swelling bentonite is primarily used by the petroleum industry as an ingredient of rotary drilling mud, and by the iron metals industry as a binder in casting molds and the pelletization of ore.

3.1.10 Sand and Gravel

Unconsolidated deposits of sand and gravel are widespread and are found throughout the State of Utah. Within the planning area, sand and gravel occur primarily as unconsolidated Quaternary sediments that are shown on Map 20. These materials are contained within four different types of mapped units (UGS, 2000):

- Alluvium and colluvium (Qa)
- Older alluvium and colluvium (Qao), including pediment deposits
- Glacial (Qg)
- Landslides (Qls)

Unconsolidated alluvial material has been deposited along virtually every river and stream course in the planning area, and occurs as raised benches and terraces adjacent to larger water bodies. Deposits mapped as older alluvium and colluvium occur mainly as pediment deposits along the base of the Book Cliffs and Wasatch Plateau (Map 20). Glacial and landslide deposits are also potential sources of sand and gravel, and occur mainly in the highlands of the Wasatch Plateau along the Emery/Sanpete County line. Eolian dunes (Qe), while considered by some to represent a potential source of sand, is generally not used for construction purposes or aggregate material but rather as a potential source of silica which is discussed under in Section 3.1.13, Miscellaneous Minerals. As shown on Map 20, eolian deposits are scattered across southeast Emery County in the Green River Desert physiographic province. Because Map 20 was derived from the Geologic Map of Utah CD published on a 1:500,000 scale, many of the smaller unconsolidated Quaternary deposits do not appear on the figure. For this reason, the outline of the principle modern stream and river courses in the planning area are also shown on Map 20.

Most of the usable sand and gravel deposits within Carbon and Emery Counties are found in the erosional pediments along the base of the Book Cliffs and Wasatch Plateau (identified as Qao on Map 12) which can exceed 100 feet in thickness. However, since much of this material is derived from Mesozoic and Tertiary shales and friable sandstones, the clasts are generally too weak to produce quality concrete or bituminous aggregate. Consequently, sand and gravel deposits within the planning area are most suitable for fill and borrow material, or general road construction purposes (UGS, 2002a). While recent alluvial deposits adjacent to active stream courses can provide quality sand and gravel, they are often inaccessible on the floors of steep sided canyons.

3.1.11 Stone

Limestone and sandstone have been quarried throughout Utah for a variety of purposes including dimension stone, building stone, crushed rock, field stone, landscape rock, railroad ballast, concrete aggregate, riprap, and numerous other industrial uses. Limestone is also quarried for use as an acid neutralizer, coal mine dust retardant, smelting flux, flue gas scrubber, cement, and refractory material. Sandstone (i.e., silica) can be also used as an abrasive; and for glass making, filters, fluxes, chemicals and electronics. However, the occurrence of silica sources in the planning area is discussed in Section 3.1.13.

While most stone quarrying in Utah takes place in the western half of the state, limestone has been quarried from the Tertiary Flagstaff Limestone west of Castle Dale on the Wasatch Plateau, for use as a dust retardant in nearby coal mines. Sandstone has also been quarried from various locations around the San Rafael Swell, primarily from the Navajo Sandstone and the Kayenta Formation, for use as decorative landscaping and building rock. In addition, other quarry areas are designated as community pit, common use areas or FUPs.

3.1.12 Humate

Humates (or carbonaceous shales) are essentially low rank and/or weathered coal deposits that contain a high amount of inorganic silt making them unsuitable for use as a fuel (UGS, 1998). The quality of the humate increases with increasing humic acid content that typically increases with the degree of weathering. The material is typically mined for use as a dietary "colloidal mineral supplement" that is sold in health food stores. After being mined, the humate is crushed and soaked in water for a period of three to four weeks at which time the leachate water is filtered off and the elixir is bottled for sale (USG, 1998). To a believer in alternative medicine, leachates from humates are touted to improve health by providing essential minerals and nutritional chemicals. The material is also mined under the name carbonaceous or humic shale.

Humate is also mined for use as a soil amendment for gardening and farming applications. Humate (being similar to peat moss) is known to increase the water holding and ion exchange capacity of the soil, aid in nutrient uptake of the plant via the humic acids, and act as a pH buffer for alkaline soils. Microorganism growth is also reported to be positively affected by the introduction of humate to soils (BLM, 1997a). Because humate is a natural geologic material, its lure as an agricultural product is based largely on its "organic" nature as an alternative to traditional chemical fertilizers.

Most, if not all, of the humate currently mined in Utah comes from the middle section of the Ferron Sandstone Member of the Mancos Shale, specifically the G bed (UGS, 1998). The Ferron Sandstone hosts the Emery coal field in Emery County (see Section 3.1.1).

3.1.13 Miscellaneous Minerals

Other geologic materials that have previously been mined within the planning area, or have potential for future development, include sulfur, semiprecious gemstones, barite, and silica.

Elemental sulfur is present on the surface as a soil cementing material in areas around the San Rafael River and Cedar Mountain in Emery County (USGS, 1969). Mineralization in these areas are typically associated with warm/cool spring deposits, and occur as a pale yellow to gray soil cementing material, or in small crystals.

Semiprecious gemstones that are found in the planning area include alabaster from the gypsum layers in the Summerville and Carmel Formations, and various species of cryptocrystalline quartz such as petrified wood, jasper, agate, and chalcedony (USGS, 1969). Most of these quartz gems occur in the Moss Back Member of the Chinle Formation (a.k.a. Shinarump Conglomerate), and in the Morrison Formation where silica saturated groundwaters replaced buried organic material or precipitated directly into void spaces. The collection of fossilized dinosaur bones is prohibited by law on all public Utah lands without a special scientific permit. Mineral material disposal regulations allow that persons may collect limited quantities of petrified wood for non-commercial purposes (i.e., free-use) under the terms and conditions consistent with the preservation of significant deposits as a public recreational resource (43 CFR 3622). In that regard, petrified wood is considered to be not only a salable mineral, but also a paleontological resource, and may be subject to protective measures accordingly.

Specimen quality blue celestite and calcite are also known from one location in southwestern Emery County (Strontium King #2, Map 8). Barite, the principal ore of barium, is present at various locations in southern Emery County where it occurs as a low temperature vein or replacement mineral, typically in association with celestite, fluorite, quartz and metallic sulfide minerals (USGS, 1969).

The planning area contains large amounts of Paleozoic and Mesozoic sandstone, and Quaternary eolian deposits that could be potential sources of silica, but there has been no development of this resource to date. Silica sand can be used as an abrasive or grit for sand blasting; and for glass making, foundry material, filters, fluxes, chemicals, and electronic components. Sandstone units with high silica content include the Cretaceous Dakota Sandstone; the Jurassic Wingate Sandstone, Kayenta Formation, Navajo Sandstone, and Entrada Formation; and, in particular, the Permian White Rim Sandstone (a.k.a. Coconino Sandstone) of the Cutler Group (UGS, 2002a). As discussed in Section 2.2.1, the Green River Desert physiographic section of the Colorado Plateau contains extensive deposits of quaternary eolian sands that are potentially amenable as a source of silica. The distribution of these geologic units is shown on Map 12.

3.2 MINERAL EXPLORATION, DEVELOPMENT AND PRODUCTION

This section of the report discusses the history of mineral exploration, prospecting and development in the planning area, and the economic significance of each mineral commodity. The potential for the occurrence and future development of these resources within the next 15 years are discussed in Section 3.3

3.2.1 Coal

As noted in Section 3.1.1, The UGS, BLM, and USGS are currently working on the NCRA project to determine the amount of coal remaining for future development in Carbon and Emery Counties. The BLM has determined that the results of this project will become incorporated into this Mineral Potential Report as soon as they are available. Attachment 4 of this document has been reserved for the inclusion of coal resource and development potential information. However, Carbon and Emery Counties contain significant coal deposits that together account for about one-third of Utah's coal resources and 90 percent of its current production.

3.2.2 Coal Bed Methane

While the CBM industry is still relatively young, it shows great potential to become a major energy source in the United States as production has increased rapidly over the past five to 10 years. Overall, CBM accounts for 7.5 percent of the total natural gas production in the U.S., but that figure is expected to rise significantly over the next several years (USGS, 2000). Since CBM was first produced in Utah in 1982, almost all of the in-state production has come from wells located in Carbon and Emery Counties. The region also has access to several pipelines that provide coal bed methane producers access to markets on the Wasatch Front and the Midwest.

The USGS conservatively estimates that that more than 700 trillion cubic feet (tcf) of CBM exists within the conterminous United States, and that perhaps 141 tcf are recoverable using existing technology (USGS, 2000). This estimate has risen significantly over estimated reserves published just a few years ago. For example, during its 1995 assessment, the USGS estimated that about 300 tcf of CBM may exist nationwide, with 50 tcf of this gas being technically recoverable.

The Emery and Book Cliffs CBM Plays are rapidly becoming one of the most productive CBM areas in the country with approximately 740 active wells producing as of December 2001, and about 100 more going into production each year (Stephens, pers. comm., 2001; UDOGM, 2002). In 2001, 109 CBM wells were completed in Carbon County (producing and shut-in), while 40 were completed in Emery County (UDOGM, 2002). The major producers of CBM in Carbon and Emery Counties are currently Anadarko Petroleum Corporation (Anadarko), Texaco Exploration and Production, Inc. (Texaco), Chandler and Associates, LLC. (Chandler), and Phillips Petroleum Company (Phillips).

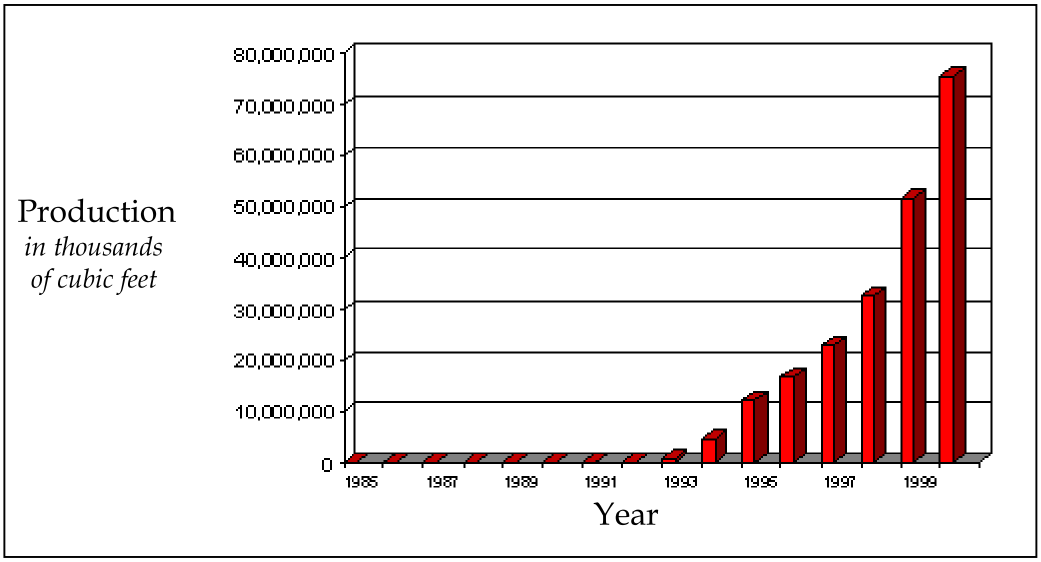
CBM was first produced in Utah in 1982 from horizontal borings drilled in existing underground coal mines (primarily the Soldier Creek Mine in the Book Cliffs), and continued sporadically through the 1980's (UDOGM, 2002). In 1991, Utah's first operation designed specifically for CBM production began with the Drunkards Wash Project located just southwest of Price, followed by the Castlegate Project in northern Carbon County (Map 16). Overall, Carbon County was Utah's third leading producer of natural gas in 2000 (72.59 bcf), with 99 percent of this production derived from CBM wells. Annual CBM production for Carbon and Emery Counties is shown in Table 6. A graph of total CBM production from 1985 through 2000 using the same data as presented in Table 6 is shown below in Table 7.

Table 6. Annual Coal Bed Methane Production for Carbon and Emery Counties.

Year	Carbon	Emery
1986	0	0
1987	8,884	0
1988	37,045	0
1989	0	0
1990	0	0
1991	76,098	0
1992	156,143	0
1993	904,731	0
1994	4,681,248	0
1995	12,206,047	561
1996	16,717,787	220,915
1997	22,527,512	355,831
1998	31,750,179	799,063
1999	49,818,645	1,840,281
2000	71,989,665	3,601,736

Source: UDOGM Internet Web Site
Production statistics in thousands of cubic feet

Table 7. Annual CBM Production in the Planning Area.



3.2.2.1 Recovery and Production

As noted in Section 3.1.2, the gas content of a coal seam generally increases with increasing rank of the coal deposit. The concentration of methane gas in a coal sample is usually determined from laboratory analyses and expressed in cubic centimeters per gram (cc/g). This figure is later converted to cubic feet per ton (cf/t) or billions of cubic feet per square mile (using isopach maps and assuming an average density of 1.32 g/cc for most Blackhawk and Ferron coals), or expressed simply as billions or trillions of cubic feet per field or play. However, the amount of CBM present in the subsurface can be significantly different than the amount that can be recovered using current technology. Coal bed gas recovery is strongly controlled not only by the gas content of the formation, but also by the permeability of the host and adsorption isotherm (USGS, 1995). Permeability can be increased by hydrofracturing or other methods, but if the coal matrix is undersaturated with respect to its gas storage capacity, significant pressure drawdown at the wellbore must occur before methane is desorbed (USGS, 1995). In addition, well interference tends to benefit CBM production where decreased well spacing tends to speed up the dewatering process resulting in more rapid gas desorption (USGS, 1995). Overall, while CBM deposits are continuous and widespread, recovery can be highly variable from well to well within a single play.

Vertical extraction wells are by far the most common method of producing CBM in areas that have not been mined. These wells commonly require special completion techniques or stimulation such as hydrofracturing, under-reaming, or open-hole cavitation. Within areas that have experienced prior underground mining activities, four types of wells are used to recover CBM (USGS, 1995):

1. vertical wells drilled from the surface in advance of mining.

2. gob wells drilled from the surface to above the coal bed prior to mining where gas is produced from the fractured zone created by the collapse of strata surrounding the mined out area.

3. horizontal boreholes drilled from inside the mine to degasify the coal bed to be mined.

4. cross-measure boreholes drilled from inside the mine to degasify the surrounding strata.

UDOGM currently permits CBM wells to be spaced on a maximum density of one well per quarter section (160 acres). Although this spacing requirement is based upon efficiency issues for CBM extraction, the density of CBM well spacing in the planning area may be increased in the future (Stephens, pers. comm., 2001). Near Rifle, Colorado, in the Piceance Basin, the BLM is currently testing 20-acre well spacing in some CBM areas (High Country News, 2002).

3.2.2.2 Book Cliffs (Blackhawk) Play

CBM in the Book Cliffs Play (USGS Play 2050) is currently being produced from the Blackhawk Formation where the total coal isopach is up to 68 feet, with an average thickness of 20 feet across the play (USGS, 1995). Individual wells are up to 6,000 feet deep, with the majority of the completions being in the 3,000-foot depth range. Since coal seams under this amount of overburden are not minable under current conditions, CBM production offers the only available opportunity to access this energy resource. The Castlegate Field, located just south of the Carbon/Duchesne County line, is the largest producer in the play (Map 16), but production here is minor as compared with that from the Drunkards Wash and Helper Fields located further south in the Emery Play.

Book Cliffs CBM can contain as much as 10 percent carbon dioxide, creating the need to purify the gas prior to placing it in the transmission pipeline. Water produced from CBM wells is moderately saline, and averages 5,500 mg/L TDS (mostly as bicarbonate). During the initial stages of development, most wells typically produce several hundred barrels of water each day, which decreases significantly after a few months of production (USGS, 1995). Most of the water produced as a consequence of CBM is injected into sandstone units both underlying and overlying the Blackhawk Formation. Early operators treated CBM production water using reverse osmosis prior to surface discharge, but this method is no longer used due to the high expense.

Desorption data from Book Cliff coal samples indicates that gas concentrations are as much as 360 cf/t at locations within 5 miles of the outcrop face, and gas content generally increases with increasing distance from the outcrop (i.e., further north). Experimental and production data also indicate that recovery is generally greater than

90 percent when gas concentrations exceed 150 cf/t, but can fall to less than 50 percent when gas concentrations fall below this threshold level (USGS, 1995, UGS, 2001).

3.2.2.3 Emery (Ferron) Play

CBM in the Emery Play (USGS Play 2052) is currently being produced from the Ferron Sandstone where the total coal isopach is up to 40 feet, with an average thickness of 13 feet across the play (USGS, 1995). Most of the extraction wells are between 1,000 and 3,000 feet deep, with some up to 4,000 feet deep (Map 16). The Emery CBM Play (also called the Ferron Fairway) is actually somewhat larger than what is identified on Map 16 because CBM wells tapping the coal seams within Ferron Sandstone are located around the towns of Price, Wellington and Huntington in what is identified by the USGS as conventional oil and gas plays. In practice however, the Emery CBM Play extends east and south to the outcrop belt of the Ferron Sandstone (Map 15). The Ferron Fairway also extends west under the Wasatch Plateau coal field and north under the Book Cliffs, but these deeper portions of the play are largely unexplored. The Drunkards Wash/Price Field is the largest producer in the play (Map 16), and was the third leading gas producer in Utah (1997 data). As described in Section 3.2.3, the Ferron Sandstone Member of the Mancos Shale also hosts conventional oil and gas reservoirs not associated with coal seams.

Water production from the Ferron Sandstone is similar in volume to Book Cliff CBM wells with initial flows of several hundred barrels per day. Water quality data from currently producing CBM wells in the Emery Play show TDS concentrations ranging from 6,000 to 23,000 mg/L, with very high concentrations of sodium (1,770 to 2,600 mg/L), chloride (1,412 to 7,450 mg/L) and bicarbonate (2,050 to 10,425 mg/L) (BLM, 1999). Groundwater pumped from the Ferron Sandstone during CBM production is either treated prior to surface discharge, or injected into sandstones underlying the Ferron such as the Jurassic Navajo Sandstone. In general, CBM wastewater is injected into formations where the groundwater quality is of an equal or lesser quality as compared to the wastewater itself. The carbon dioxide content of Emery CBM is lower as compared to Book Cliff production, and averages only 3 to 4 percent (Stephens, pers. comm., 2001).

Production of CBM from the Emery Play (or Ferron Fairway) has far outdistanced that from the Book Cliffs. CBM produced from the Emery field currently accounts for about 99 percent of the total Carbon County production (Table 6). The northern portion of the Emery Play (i.e., in Carbon County) has seen the most development of CBM projects. Of the year 2000 production totals from Carbon County identified in Table 6, approximately 90 percent of that total came from the Drunkards Wash and Helper Fields location just outside of Price. The Buzzard Bench field was the leading CBM producer in Emery County.

3.2.3 Oil and Gas

There is a long history of hydrocarbon exploration in the planning area that dates back to 1899 (UGA, 1990). In addition, oil and gas shows have been found in a wide variety of rock types, from Paleozoic to Tertiary age, and across many parts of the planning area. This is in part due to the large overall thickness of the Phanerozoic sedimentary section, which exceeds 9,000 feet in thickness across many parts of the planning area (Attachments 1 and 2). Despite these facts, conventional oil and gas production (i.e., excluding CBM) from Carbon and Emery Counties has been relatively insignificant over the years, and gas production has far outweighed oil production.

As discussed in Section 3.1.3, The USGS has defined 10 conventional oil and gas plays that occur within the planning area. Within these plays, there are a number of fields that are individual producing units consisting of either a single pool or multiple pools of hydrocarbons related to a single structural or stratigraphic feature (USGS, 1995). Overall, there are some 19 separate conventional oil and gas fields that have been identified and developed within the planning area, of which nine are still active. UDOGM defines an active field as containing one or more active wells, including those in a producing, shut-in, and temporarily abandoned status. The activity status and production statistics for conventional oil and gas field present within the planning area are summarized below in Table 8, and are shown on Map 21. The San Rafael Swell itself (i.e., the physiographic feature), and southeastern Emery County, are the only regions of the planning area where oil and gas fields have not been discovered. This is partly because the Cretaceous and Tertiary strata have been removed by erosion, and there are no suitable structural or stratigraphic traps within the Lower Mesozoic and Upper Paleozoic section. As discussed in Section 3.1.4, the erosion of younger strata on the San Rafael Swell has converted conventional oil and gas accumulations into resultant tar sand deposits.

Table 8. Conventional Oil and Gas Fields in Carbon and Emery Counties

Field Name	Status[6]	County	Major Producing Formation(s)	2000 Production		Cumulative Production	
				Oil (bls)	Gas (mcf)	Oil (bls)	Gas (mcf)
Clear Creek	Active (9)	Carbon/ Emery	Ferron Sandstone	0	384	0	114,376,127
Dry Creek	Active (2)	Carbon	Wasatch/Colton	0	63,376	1,826	1,297,856
Gordon Creek	Inactive	Carbon	Ferron Sandstone	0	0	0	0
North Spring	Inactive	Carbon	Ferron Sandstone	0	0	0	0
Flat Canyon	Active (6)	Emery	Ferron/Dakota	0	258,741	14,719	8,741,759
Marsing Wash	Active (1)	Carbon	Ferron Sandstone	0	49,061	0	NA
Farnham Dome	Aband.	Carbon	Navajo	0	0	0	2,053,449[1]
Grassy Trail	Active (20)	Carbon/ Emery	Moenkopi	3,279	1,574	548,763	154,051
Stone Cabin	Active (3)	Carbon	Wasatch/Colton	0	98,798	22	777,467
Prickly Pear	Inactive	Carbon	Mesaverde	0	0	0	183,388
Nine Mile Canyon	Active (2)	Carbon	Wasatch/Colton	0	33,201	0	670,791

Table 8. Conventional Oil and Gas Fields in Carbon and Emery Counties

Field Name	Status[6]	County	Major Producing Formation(s)	2000 Production		Cumulative Production	
				Oil (bls)	Gas (mcf)	Oil (bls)	Gas (mcf)
Peters Point	Active (9)[7]	Carbon	Green River & Wasatch/Colton	211	289,528	150,596	5,260,934
Unnamed 27-12S15E	Inactive	Carbon	Wasatch/Colton	0	0	1,432[2]	521,146[2]
Miller Creek	Aband.	Carbon	Ferron/Dakota	0	0	0	0
Woodside[3]	Aband.	Emery	Kaibab/Cutler	0	0	0	0
Ferron	Active (16)	Emery	Ferron Sandstone	0	78,707	38,470	11,512,988
Indian Creek	Inactive	Emery	Ferron Sandstone	0	0	3,963[2]	2,474,521[2]
Last Chance	Inactive	Emery	Moenkopi	0	0	0	750
Buzzard Bench	Active[5](3)	Emery	Ferron Sandstone	0	0	0	8,502[4]

Notes:
Aband. = Abandoned
NA = Information not available
1 = Gas production mostly carbon dioxide
2 = Production statistics as of 1990
3 = Production of inert gas including nitrogen, carbon dioxide and helium.
4 = Production statistics as of 1990 (not including CBM)
5 = Primarily a CBM field
6 = The number in parenthesis represents the number of active wells (including producing, shut-in, and temporarily abandoned)
7 = In 2001, one well was spudded (drilling commenced in the Peters Point field.
Information Source: (UDOGM, 2002)

Many of the oil and gas fields in the planning area are small, and have only one well (e.g., Nine Mile Canyon, Prickly Pear, and North Spring)(Map 21). Grassy Trail is currently the largest producing field in the planning area (and historically the largest oil producer) with 10 active wells currently producing (UDOGM, 2002).

The majority of the gas currently produced in the planning area is from sandstone and coal beds in the Ferron Sandstone. Small quantities of oil are produced in Carbon County from the Green River and Wasatch Formations, while the Moenkopi is the largest oil producer in Emery County. Gas production had been declining in both counties until the early 1990's when rapid CBM exploration began in the Ferron Sandstone and Blackhawk Formation. Oil production continues to decline in both counties, and since 1980, all new field discoveries in the planning area have been gas producers. In addition, only a few miles of seismic lines have been permitted since 1989, indicating that structural traps have not been significant exploration targets (UGS, 2002a). In general, few new oil and gas wells have been permitted in the planning area until drilling for CBM began in the early 1990's. Table 9 shows drilling trends and well completion types in the planning area through 1998 (UGS, 2002a)

Table 9. Oil and Gas Well Completions in Carbon and Emery Counties

Type of Completion	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Oil Wells	0	0	0	0	0	0	0	0	0	0	0
Gas Wells	1	1	5	0	13	45	42	21	20	59	84
Service Wells	0	0	0	0	0	0	1	0	3	4	0
Temporarily Abandoned	1	0	0	0	0	0	0	0	0	0	0
Plugged and Abandoned	1	4	1	1	1	3	1	3	2	2	0
Stratigraphic Tests	0	0	0	0	5	0	4	0	0	0	0

Table 9. Oil and Gas Well Completions in Carbon and Emery Counties

Type of Completion	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total Wells	3	5	6	1	19	48	48	24	25	65	84
Success Ratio (excluding stratigraphic tests)	33%	20%	83%	0%	93%	94%	98%	88%	92%	97%	100%
Average Depth Drilled (ft)	3,808	3,162	5,267	1,932	2,591	3,539	2,769	2,189	4,340	3,270	3,126

A review of the information presented on the UDOGM Internet web site indicates that a total of eight gas wells (not including CBM wells) have been spudded (drilling commenced) in 2002. Information on these eight wells is summarized in Table 10.

Table 10. Spudded Gas Wells in Carbon and Emery Counties (2002)

Field Name	County	API Well #	Operator	Well Name	Lat.	Long.
Peters Point	Carbon	43—007-30709-00-00	Bill Barrett Corp.	Peters Point 3A	39.70256	-110.0374
Clear Creek	Carbon	43-007-30808-00-00	Clear Creek LLC	Cook 20-1	39.6806	-111.1561
Clear Creek	Emery	43-015-30271-00-00	Edward Mike Davis	Ridge Runner 11-20	39.59033	-111.1666
Clear Creek	Emery	43-015-30269-00-00	Edward Mike Davis	Ridge Runner 13-17	39.60164	-111.1715
Gordon Creek	Carbon	43-007-30724-00-00	Klabzuba Oil & Gas Inc.	Gordon Creek ST 19-14-8	39.59525	-111.0723
Gordon Creek	Carbon	43-007-30725-00-00	Klabzuba Oil & Gas Inc.	Burnside 29-14-8	39.58442	-111.0482
Undesignated	Carbon	43-007-30818-00-00	EDP Resources LLC	EDP 1	39.5366	-110.5847

Note: Spudded gas wells do not include CBM wells. No oil wells spudded in the planning area during 2002.

Provided below is a brief description of each of the 10 active oil and gas fields within the planning area as obtained from the UDOGM internet web site and UGA Publication No. 19 (UDOGM, 2002; UGA, 1990). Details of each oil and gas field in Utah; including drill hole, reservoir, well and general field data are provided in UGA Publication No. 22 (UGA, 1996).

3.2.3.1 Buzzard Bench

Located in the Castle Valley of western Emery County, Buzzard Bench is primarily a CBM field (see Section 3.2.2), but conventional gas has been produced along shallow structural closures within the Ferron Sandstone, and from lenticular fluvial/deltaic facies sandstone facies. There are currently three active wells producing conventional gas where annual 2000 production was 102,052 mcf (UGS, 2002b).

3.2.3.2 Clear Creek

Located on the Wasatch Plateau and discovered in 1951, the Clear Creek field hosted the first commercial production of hydrocarbons in east-central Utah. Despite low primary porosities and permeabilties in the Ferron Sandstone, fracturing due to folding and faulting has improved reservoir characteristics. Producing depths are between 4,600 and 4,800 feet where there are combined structural/stratigraphic traps in a complexly faulted, doubly plunging anticline. Production is from the Ferron Sandstone Member of the Mancos Shale.

3.2.3.3 Dry Creek

Located in northeast Carbon County (Sec. 27, T. 12 S., R. 15 E.), the Dry Creek field was discovered in 1988 and produces from stratigraphic traps in the Wasatch/Colton Formation.

3.2.3.4 Ferron

Located in the Castle Valley of western Emery County, shallow gas production was established from the Ferron Sandstone in 1957, and oil and gas production from the Permian Kaibab Formation began in 1964. Production from the Kaibab is currently shut-in. Shows have also been reported from the Dakota Sandstone, the Moss Back Member of the Chinle Formation, and the White Rim Formation of the Cutler Group. The Ferron oil and gas field involves both structural and stratigraphic traps. Structurally, the field is a north-northeast trending anticlinal fold with two structural highs: one with about 130 feet of closure (north high), and one with 70 feet of closure (south high). Stratigraphic entrapment is caused by lenticular sandstone and interbedded shales deposited in a fluvial-deltaic environment. The recently completed "Ferron Project" was an interagency study of the Ferron Sandstone involving members of the UGS, USGS, academia, and industry. The project was initiated in 1993 with the goal of improving oil field development in similar reservoirs worldwide through detailed stratigraphic and facies analysis.

3.2.3.5 Flat Canyon

Located on the Wasatch Plateau and discovered in 1953, Flat Canyon did not produce gas until 1985. This oil and gas field sits atop of the Flat Canyon Anticline, a northeast trending structure with about 250 feet of closure. Fault closures result in additional structural traps, but stratigraphic traps exist as well. Joes Valley Graben truncates the field on the west. Production is derived from both the Ferron Sandstone and the Dakota Sandstone, with open holes drilled to depths of approximately 7,000 feet where individual producing beds are typically 10 to 20 feet thick.

3.2.3.6 Grassy Trail

The Grassy Trail field is located on a small structural nose at the north end of the San Rafael Swell (the Mounds anticline), and produces from several zones in the lower members (Torrey and Polack Members) of the Triassic Moenkopi Formation. This field has been the largest producer of oil in the planning area, and currently has 20 active wells, 10 of which are producing. Producing beds are typically 10 to 20 feet thick. Source rock is unknown.

3.2.3.7 Marsing Wash

Consisting of only a single well, this small field in western Carbon County is located at Township 15 S, Range 9 E, Section 34 and produces from the Ferron Sandstone. No other information is available. This field is sometimes assigned to Drunkards Wash which is primarily a CBM field on the Ferron Fairway.

3.2.3.8 Peters Point

This field was discovered in 1953, and is located along the Jack Canyon anticline, a northwest trending, doubly plunging structure about 30 miles long with a maximum closure of about 250 feet. However, traps are both structural and stratigraphic. Production is primarily from the Wasatch/Colton Formation, although production has also been derived from the Green River Formation, the Mesaverde Group, the Mancos Shale and the Dakota Sandstone. Individual producing beds are typically less than 20 feet thick.

3.2.3.9 Stone Cabin and Nine Mile Canyon

Both of these fields lie along the northwest plunge of the Jack Canyon anticline, a doubly plunging structure in northern Carbon County. Production from the Wasatch/Colton Formation was established at Stone Cabin in 1960, and two years later at Nine Mile Canyon. These fields contain reservoirs and traps similar to that at Peters Point.

3.2.3.10 Other Inactive or Abandoned Fields

The Gordon Creek, Farnham Dome and Woodside fields are closed anticlines that have tested and/or produced large volumes of inert gas, primarily carbon dioxide and nitrogen. Each of these structures is superimposed on the north end of the much larger San Rafael anticline. The Woodside anticline is a north trending structure with about 800 feet of closure. Drilling in the 1920's discovered carbon dioxide and helium (approximately 1.3% He) in the Cedar Mesa Sandstone Member of the Cutler Group (a.k.a. Coconino Sandstone), and in 1924 this area was established as U.S. Helium Reserve No. 1. Inert gas was also produced from the Kaibab Formation in the Woodside field, with shows of flammable gas from the Pennsylvanian Hermosa Group. In the Gordon Creek field, carbon dioxide is derived from the Cedar Mesa Sandstone and the Moenkopi Formation, while flammable gas was produced from the Ferron Sandstone. The Farnham Dome produced approximately 4.76 bcf of carbon dioxide from the Navajo Sandstone, and gas is also present in the Moenkopi Formation. While metamorphism of carbonate rocks is the likely source of carbon dioxide in these fields, degassing Precambrian basement rock is probably responsible for producing the nitrogen and helium (UGA, 1996). The Woodside and Crystal Terrace "geysers," located along U.S. Highway 6 between the towns of Woodside and Green River, are explosive groundwater systems where carbon dioxide rapidly exsolves.

The Last Chance field lies along the northwest trending Last Chance anticline located along the southwestern flank of the San Rafael Swell. The field was discovered in 1934, and minor gas production was initiated from the Moenkopi Formation. Oil and gas shows have also been reported from the White Rim Sandstone (Coconino) of the Cutler Group.

3.2.4 Solid Hydrocarbons

The tar sand and oil shale deposits in the southern and eastern portions of the Uinta Basin are the largest accumulations of their type in the country (USGS, 1969). It has been estimated that Utah's tar sand deposits contain approximately 25 billion barrels of bitumen in place, a figure that is roughly equal to one quarter of recoverable crude oil reserves in the United States (UGS, 1996; USGS, 1995). Similarly, oil shales in the Uinta Basin contain an estimated potential oil yield of 320 billion barrels (USGS, 1969). Despite this enormous energy development potential, large-scale commercial production of oil from solid hydrocarbons has not occurred in this country beyond the demonstration stage or constructing pilot projects. The success of Canadian tar sand operators, along with some oil shale mines in Sweden and South Africa, has sparked widely fluctuating interest in developing Utah's solid hydrocarbons by U.S. companies. However, the availability of comparatively cheap conventional petroleum, along with contentious land use policy issues concerning large surface mines, has negated consideration of developing this resource. If development were to take place, it would likely occur through either surface quarries or underground mines. However, Shell Oil Company has recently tested in-situ thermal techniques for oil shale recovery in the Piceance Basin of Colorado (Kohler, pers. comm., 2002)

3.2.4.1 Tar Sands

UGMS has divided Utah's tar sand accumulations into three separate occurrence zones as follows (UGMS, 1983):

Zone 1: Areas with known outcrop of bitumen-rich to very rich tar sands, or areas where bitumen-rich zones can be readily projected based upon outcrop measurements or drill hole data.

Zone 2: Areas that are likely completely underlain by bitumen-rich tar sands as inferred from outcrop or drilling data.

Zone 3: Areas that are likely underlain by discontinuous bitumen-rich tar sands or low-grade deposits.

These tar sand occurrence zones (or grade maps) are shown on Map 22 for the deposits located in the planning area. These include the giant Sunnyside deposit in Carbon County, along with the adjacent Cottonwood-Jacks Canyon area, and the smaller Minnie Maud and Nine Mile Canyon areas along the Carbon/Duchesne County line. The Peters Point, Nine Mile Canyon, Prickly Pear and Stone Cabin conventional oil and gas fields are all located on small anticlinal features, on or adjacent to the Cottonwood-Jacks Canyon tar sand area. As noted in Section 3.1.4, these deposits occur within the lower section of the Green River Formation, and the upper parts of the Wasatch/Colton Formation. Ten of the tar sand deposits on the San Rafael Swell are also named, and include: Red Canyon, Black Dragon, Wickiup, Cottonwood Draw, Justensen Flats, San Rafael Swell, Flat Top, Family Butte, Temple Mountain, and Chute Canyon (Map 22). As described in Section 3.1.4.1, these deposits are hosted by a variety of Mesozoic rocks, primarily the Black Dragon Member of the Moenkopi Formation; and the Moss Back (Shinarump Conglomerate) and Temple Mountain Members of the Chinle Formation (USGS, 1988a, 1990). Most of the areas that are occupied by Zones 1 and 2 on Map 22 have been designated by Congress as Special Tar Sand Areas (STSAs) as a consequence of the Combined Hydrocarbon Leasing Act of 1981.

Published literature suggests that Sunnyside is the only tar sand deposit in the planning area that has seen commercial development; although some "mom and pop" type development operations have occurred elsewhere (UGS, 1996; USGS, 1988, 1990). All development to date has been through surface quarries where good bitumen-rich outcrop is exposed (e.g., Zone 1, Map 22).

Tar sands from the Sunnyside deposit were intermittently mined from 1892 until the late 1940's when most of these small-scale development operations closed (UGS, 1996). The majority of this rock was used for road base construction and paving material in Utah and surrounding western states. An estimated 335,000 tons of rock material was quarried, primarily from the lower portion of the Green River Formation where bitumen-rich beds are exposed in outcrop in the Roan Cliffs (Map 22). The largest of these quarries was located in the Roan Cliffs around the headwaters of Water Canyon (N ½ T. 14 S., R. 14 E.). Ore from this quarry was carried by a three-mile long aerial tram, and then trucked to the rail head in the town of Sunnyside (UGS, 1996). Only tar sands that contained greater than eight percent bitumen, or where at least half of the pore spaces were filled by bitumen, were considered worth mining. From the early 1960's until the mid 1980's, several oil companies were involved in resource assessment and pilot scale tar sand demonstration projects in the Sunnyside deposit. None of these projects are currently operating.

The west-central portion of the Sunnyside is the most saturated portion of the deposit, and contains an estimated 600,000 barrels of oil per acre (UGS, 2002a). Overall, in-place reserve estimates for the Sunnyside/Cottonwood-Jacks Canyon deposit range from 728 million barrels, to 5.85 billion barrels of oil.

3.2.4.2 Oil Shale

Through the thermal retorting process, oil yields from the Mahogany ledge zone of the Green River Formation range from less than one gallon per ton, up to 95 gallons per ton of ore rock (USGS, 1969). An oil shale sequence at least 15 feet thick, that will yield an average of 15 gallons of oil per ton of ore rock underlies approximately 3,000 square miles in the Uinta Basin, including the northeast corner of Carbon County (Map 18). Additional lower grade oil shale resources are present within the Green River and Colton Formations throughout eastern Carbon County. Since the Mahogany ledge zone is thicker and richer in grade in areas east of the Green River, most of the oil shale literature is from Uintah County where detailed isopach maps have been drawn for areas yielding at least 25 gallons of oil per ton (UGMS, 1983). However, no such maps exist for oil shale deposits within the planning area. Although commercial oil shale mining has not yet occurred in Utah, development would likely occur through either surface quarries, or in underground mines in areas with less than 3,000 feet of overburden (BLM, 1984). In Carbon County however, the overburden thickness would generally make open pit mining infeasible, and would require more expensive underground mining or in-situ extraction methods.

3.2.5 Uranium and Vanadium

This section of the report describes the history of uranium and vanadium mining in the planning area, and the various mining areas and districts in Emery County.

3.2.5.1 Mining History

Radioactive ores in Utah were first mined for radium, then for vanadium, and finally for uranium. In addition, a variety of other metals (primarily copper) were produced as a by-product. Shortly following the discovery of radium in 1898, radioactive deposits in southeast Utah were mined from carnotite ores primarily for use in the medical industry. By 1910, metallurgical processes for refining radium had improved to the point where the demand for carnotite was rapidly accelerating. On average, approximately one gram of radium was present in every 200 to 300 tons of ore containing at least 2 percent of uranium oxide (U_3O_8) (USGS, 1969). During these early years of carnotite mining, the Temple Mountain deposit in Emery County was one of the country's leading producers of radium, where the market price for purified radium salts ranged from a staggering $70,000 to $180,000 a gram (UGS, 1990). In 1923, the price of radium collapsed after high-grade ore from the Belgium Congo entered the market resulting in the closure of all Utah's mines. From 1900 to 1923, Utah mines produced an estimated 12 to 15 grams of enriched radium salts (approximately 5 percent of the nations total), perhaps a quarter of which was produced from mines located in Emery County (UGS, 1990).

In the mid 1930's the mining of radioactive ores was revived by the emerging vanadium market where the metal was used in the production of specialized steel alloys. Demand for vanadium increased rapidly for the next decade, and was further stimulated by the U.S. entry into World War II. During this time, many new mines opened in Emery County; however, the Moab area in San Juan County was Utah's leading vanadium producer from mines hosted by the Salt Wash Member of the Morrison Formation. Vanadium mining continued in Emery County until about 1944 when the market became glutted and mining ceased; however, many mines reopened in 1948 when the Atomic Energy Commission established a guaranteed price schedule for uranium ore, along with additional benefits and bonuses (USGS, 1969). Initially, uranium ore was obtained from vanadium mine tailings, but these supplies were quickly exhausted and many new mines soon opened. Production peaked in 1957, at which time the federal government discontinued their bonus and incentive program, but a second uranium mining boom occurred from the late 1970's through the early 1980's as the need for fuel for commercial nuclear power plants increased. Due to the continued weak market for uranium combined with cheap foreign supplies, all mining activity has been shut down in Utah since the late 1980's. However, small quantities of uranium and vanadium are still produced as a by–product to copper mining at the massive Bingham Canyon open pit mine in Salt Lake County. While copper occurs in close association with uranium/vanadium deposits in Emery County, it was only produced in small quantities as a by-product of mining radioactive ores, and copper-bearing zones would not be minable for copper alone. According to Commodity Resource Information Board (CRIB) data, other metals including cobalt, lead, zinc and iron were also produced in association with uranium-vanadium (UGS, 1999a, 2002).

From 1948 through 1970, Emery County was Utah's second leading producer of uranium-vanadium ore next to San Juan County, and produced 1.1 million tons ore containing 5.3 million pounds of U_3O_8 (0.24 percent) along with 5.7 million pounds of V_2O_5 (0.53 percent) (UGA, 1990). This is roughly one tenth of the production derived from San Juan County mines. There is currently no exploration or development of uranium resources in Utah.

3.2.5.2 Mining Areas

Nomenclature for designating uranium mining areas and districts has been inconsistently used throughout the literature leading to confusion regarding mine locations and production statistics (UGMS, 1978, 1983; USGS, 1990a; UGS, 2002a). This section of the Mineral Potential Report presents the naming scheme for Emery County uranium mining regions in common usage by the UGS (UGS, 2002a). These uranium/vanadium mining regions are shown on Map 23.

Map 23 shows the location of historic uranium mines and prospects, and differentiates between host formation and the relative size of each mine. As shown on Map 23, 11 separate uranium-vanadium mining areas and/or districts have been identified in Emery County as follows:

1. Cedar Mountain Mining Area
2. Calf Mesa Mining Area
3. San Rafael District
4. West San Rafael Area
5. San Rafael River Area / Green River District
6. Sinbad Mining Area
7. Tomsich Butte Mining Area
8. Temple Mountain District
9. Wildhorse Mining Area
10. Delta Mining Area
11. Mineral Canyon Area / Green River District

With the exception of the West San Rafael and Cedar Mountain mining areas, all of the uranium production from Emery County has been dominated by deposits hosted by the Salt Wash Member of the Morrison Formation or the Moss Back Member of the Chinle Formations (Map 23). In the San Rafael West Area, small mines and prospects have been worked in the Summerville Formation and the Entrada Sandstone, while the Cedar Mountain Formation has been worked further north (Map 23).

Small prospects has also been reported from the lower section of the Wasatch Formation in northeast Emery County, and the black shales of the Mancos Shale have also stimulated some prospecting interest, but no mines have ever produced uranium ore from these units (USGS, 1969). Within the Moss Back Member of the Chinle Formation, uranium mineralization is more dominant towards the base of section, and mineralized channel sequences are seen incised into the underlying Moenkopi Formation in places (USGS, 1990a).

The three most productive uranium mining regions in Emery County were: 1) the Tidwell mineral belt of the San Rafael River Area; 2) the Temple Mountain District; and, 3) the Delta Mine (UGMS, 1978; U.S. Bureau of Mines, 1989; UGS, 2002a; USGS, 1990a). The Tidwell mineral belt is hosted by the Salt Wash Member, and is located approximately 10 miles west of the town of Green River, Utah, along the Tidwell Draw. The Temple Mountain District is hosted by the Moss Back Member and is located high on the San Rafael Reef (approx. 6,000 feet) about 7 miles west of State Route 24. The Delta Mine is located along Muddy Creek in southeast Emery County. The Tomsich Butte Mining Area has been another big uranium producer, and is thought to represent a major paleochannel sequence within the Moss Back fluvial system that currently trends about N10^{o}E, and extends for approximately eight miles (Map 23).

3.2.5.3 Production and Reserves

Well over 100 uranium-vanadium mines have previously operated in Emery County, and both surface and underground mining methods have been used. Overall, there have been approximately 200 producing uranium mines in Emery County, not all of which are shown on Map 23 generated using the BLM's Premier GIS database (BLM, 2002b). In addition, hundreds of other prospects have been worked where uranium-vanadium occurrence has been documented. Initially, relatively small quarries and pits were used to extract radium and vanadium ore, but by the mid 1940's exploration drilling and underground mining were common with the majority of mine entrances being accessed through adits and inclines. Some of these underground mines were up to 20,000 feet in length, but most were considerably shorter (UGMS, 1978). Vertical mine shafts were less common, but some were up to 640 feet deep in places where host rocks dip steeply. Individual ore bodies rarely exceed 10 feet in length or width, and historic mining was focused in areas where ore bodies coalesced to lengths of up to several hundred feet (BLM, 1982).

Overall, total historic uranium production in and around the San Rafael Swell was approximately 7 million pounds of U_3O_8 ore. Of this total, approximately 3.1 million pounds were produced from the San Rafael River Area, 1.5 million pounds from the Temple Mountain District, 0.9 tons from the Delta Mine, and 1.6 million tons from all other sources (U.S. bureau of Mines, 1989). Average ore grade ranges from 0.1 to 0.4 percent U_3O_8. In addition, about 5.4 million pounds of V_2O_5 were produced in the San Rafael River Mining Area. These totals are somewhat different from those reported above for Emery County as a whole by the UGA (1990a). In general, uranium production statistics should only be considered approximate due to a variety of factors including: 1) the inconsistent use of mine and mining district names; 2) individual mines reporting production under a variety of names; and, 3) different mines using the same name. For example, Table 11 presents uranium and vanadium production in Emery County as summarized by the UGS (2002a). However, as shown in Table 11, these production totals are similar to those noted above.

Table 11. Uranium and Vanadium Production in Emery County.

Year	U_3O_8 (lbs)	U_3O_8 (% Grade)	V_2O_5 (lbs)	V_2O_5 (% Grade)
1900-1941	162,735	1.0-1.2	77,000	0.9-4.0
1942-1946	9,000	0.78	5,000	0.32
1948-1953	865,902	0.26	1,553,639	0.61
1954-1979	5,250,116	0.21	4,398,291	0.18
1980-1982	776,738	0.19	6000,000	Unknown
1983-1988	770,500	Unknown	555,000	Unknown
Totals	**7,834,991**		**7,188,930**	

Source: (UGS, 2002a)

Uranium from Utah's mines was recovered by conventional mining and milling techniques that also produced small amounts of other metals (principally copper) as a by-product. In-situ leaching of uranium, while practiced to a limited extent in Texas and Wyoming, has not been used in Utah. This process involved injecting ammonium carbonate solutions into the subsurface, and removing the leachate using extraction wells, followed by precipitating the metal in ion exchange columns (U.S. Bureau of Mines, 1989).

As with production statistics, ore reserve estimates vary widely depending on the published source. The UGS estimates approximately 507,000 tons of uranium/vanadium ore remain in Emery County with an average U_3O_8 grade of 0.196 percent (UGS, 2002a). The San Rafael River Mining Area alone has a reported proven reserve of 23,000 tons of ore at a 0.12 percent U_3O_8 grade, with an indicated reserve of 43,000 tons (BLM, 1982; UGMS, 1978).

3.2.6 Precious and Base Metals

Due to the general lack of igneous or metamorphic activity, Carbon and Emery Counties are poorly endowed with metallic mineral resources. As described in Section 3.1.5 and 3.1.6, most of the metal deposits in the planning area are associated with radioactive mineral occurrences in the San Rafael Swell area of Emery County. In these areas, small amounts of various precious, base, and rare-earth metals have been extracted as a by-product to uranium-vanadium mining. While these mining areas are scattered throughout the San Rafael Swell region, three metal ore mining areas have been loosely defined in Emery County that are somewhat similar in name and extent to the uranium mining areas discussed in the previous section (UGMS, 1978; UGS, 1999b; U.S. Bureau of Mines, 1989; USGS, 1990a). These mining areas are:

1. The San Rafael River mining area on the northeast margin of the swell between the Tidwell Draw and U.S. Highway 6 (T. 21 S., R. 14 E.).

2. The Temple Mountain mining area located high on the San Rafael Reef (Approx. 6,000 feet) about 7 miles west of State Route 24 (Sec. 35, T. 24 S., R. 11 E). This area has also been referred to as the southeastern mineral belt of the San Rafael Swell.

3. The Tomsich Butte and Lucky Strike Mining areas on the west side of the San Rafael Swell, and areas immediately east to the McKay Flats (T. 24 E., R. 9 E & 10 E.). This area has also been referred to as the southwestern mineral belt for of the San Rafael Swell.

The Morrison and Chinle Formations host most of these metal deposits where mineralizing fluids were emplaced at low temperature following deposition of the clastic material. However, in the Temple Mountain area, metaliferous deposits (including gold) are also associated with collapse structures that may be related to hydrothermal activity and breccia pipes (U.S. Bureau of Mines, 1989a; USGS, 1969, 1990a). In the Tidwell Draw area 10 miles west of the town of Green River, low-grade metal deposits (primarily copper) also occur in the Entrada and Dakota Sandstones.

Map 24 shows mines that have been developed primarily for metals production as opposed to uranium ores. This information is based upon the CRIB, and the Automated Geographic Reference Center (AGRC) data obtained from UGS' internet web site and information published on CD (UGS, 1999a, 2002, 2002a). Accordingly, this information represents a compilation of UGS, USGS and BLM databases. Additional information on gold and silver/gold deposits in the planning area was obtained from UGA and UGS hard-published sources (UGA, 1990; UGS, 1999c).

Although most of the metal deposits in the planning area are associated with radioactive ores in the San Rafael Swell area, metaliferous rocks do occur elsewhere, but most of these deposits have seen only prospecting, limited production from small mine workings, or are unproven prospects. These areas include:

1. The Cedar Mountain mining area located immediately north of the San Rafael Swell (T. 18 S., R. 11 & 12 E.).

2. Scattered placer workings in alluvial sediments and pediment deposits.

3. Disseminated gold in the Mancos Shale

4. Metaliferous deposits on the west side of the San Rafael Swell.

5. Paleochannel (placer) deposits.

The Cedar Mountain mining area has seen prospecting and limited mining activity for a variety of metals, primarily from the Cedar Mountain Formation, Morrison Formation, and the Navajo Sandstone. The most common commodities are manganese and iron where they occur in ores of limonite, pyrolusite nodules, jarosite and hematite (UGS, 1999a). Several of the deposits in the Cedar Mountain area occur along faults and fractures, and small amounts of precious metals have also been extracted along the axis of the San Rafael Anticline on the east end of the area (UGS, 1999b; USGS, 1988a).

On the west side of the San Rafael Swell, there are metal deposits (primarily copper and manganese) that are not associated with radioactive occurrences. Most of these deposits are hosted by the Navajo Sandstone where secondary mineralization with malachite, azurite, limonite, jarosite and hematite has occurred (UGS, 1999a). Overall, copper (with associated silver) and manganese have been produced in greater quantities than any other metal in Emery County. Copper occurrences (not associated with uranium or vanadium) consist mostly of azurite and malachite along bedding planes, fractures and faults in Triassic and Jurassic sandstones. Copper and silver occurrences in the planning area, arranged by decreasing age of host rocks in a north to south direction, are summarized in Table 12.

Table 12. Copper and Silver Occurrences in the Planning Area.

Name	Location		Host Formation
	UTM N	UTM E	
Red Canyon	4323000	535840	Chinle Formation
Chimney Rock 3	4343425	542825	Navajo Sandstone
Chimney Rock 2	4343375	542450	Navajo Sandstone
Chimney Rock 1	4343300	541215	Navajo Sandstone
Chimney Rock 4	4341950	541720	Navajo Sandstone
Bob Hill Knoll	4334150	524500	Navajo Sandstone
Sorell Mule	4327460	515120	Navajo Sandstone
Copper Globe	4294660	507680	Navajo Sandstone
ZCMI	4311540	513550	Kayenta Formation, Wingate Sandstone
Alice East	4318290	552600	Entrada Sandstone
Alice	4318100	552370	Entrada Sandstone
Primrose North	4317700	552450	Entrada Sandstone
Primrose South	4316800	552840	Entrada Sandstone
Flaming Star	4301600	546800	Entrada Sandstone

Source: (UGS, 2002a)

Most of the past exploration and production of copper was through surface activity, with some minor development of shallow shafts, adits and pits. Total production of copper and silver in Emery County through 1952 was 8,350 pounds of copper and 368 ounces of silver (UGS, 2002a). Minor amounts of lead were also recovered from some of the locations identified in Table 12. There is currently no exploration or production activity for copper or silver in the planning area.

Eighteen, small manganese deposits are known from Emery County that are hosted by the Summerville formation, the Brushy Basin Member of the Morrison Formation, and the Cedar Mountain Formation (UGS, 2002a). These low grade (up to 25 percent), sedimentary-hosted deposits consist mainly of nodules in limey sandstones and sandy shales. These deposits, arranged by decreasing age of host rock in a north to south direction, are summarized in Table 13.

Table 13. Manganese Occurrences in the Planning Area.

Name	Location		Host Formation
	UTM N	UTM E	
Dry Lake Wash A	4295340	568660	Summerville Formation
Dry Lake Wash B	4294930	568010	Summerville Formation
Dry Lake Wash C	4294880	567750	Summerville Formation
Red Cloud	4294970	567520	Summerville Formation
Rochester	4311210	495730	Morison Formation
South Rochester A	4309100	494450	Morison Formation
South Rochester B	4308800	494420	Morison Formation
Snow A	4294960	484380	Morison Formation
Snow B	4294960	484420	Morison Formation

Table 13. Manganese Occurrences in the Planning Area.

Name	Location		Host Formation
	UTM N	UTM E	
Snow C	4294850	484460	Morison Formation
Snow D	4294820	484460	Morison Formation
Snow E	4294780	484470	Morison Formation
Snow F	4294770	484560	Morison Formation
Cedar Mountain B	4340460	527250	Cedar Mountain Formation
Cedar Mountain C	4339550	524700	Cedar Mountain Formation
Cedar Mountain D	4342300	523725	Cedar Mountain Formation
Cedar Mountain A	4347650	521650	Cedar Mountain Formation
Saucer Basin	4275500	571500	Recent gravel deposits

Source: (UGS, 2002a)

Total historical production of manganese ore in Emery County is approximately 800 tons, most of which was produced during 20th Century war times when the government price supports were in place (UGS, 2002a). There is currently no exploration or development activity for manganese in the planning area.

There are no well documented occurrences of gold in Carbon or Emery County (UGS, 2002a). Prospectors of the late 19th and early 20th centuries made sporadic attempts to recover placer gold from the unconsolidated sediments along the banks of the Green River, but the source of this gold is unknown (UGMS, 1966). While small quantities of gold are present, there is little evidence of a resource present in these sediments (USGS, 1988a). There was an active placer gold operation located on the west bank of the Green River just south of the Interstate 70 crossing, but its closure date is unknown (UGA, 1990).

Scattered throughout Emery County, paleo-placer deposits have been prospected from various Mesozoic fluvial deposits with very little success. Stratigraphic units that have been worked include the Cedar Mountain, Morrison, Kayenta, and Chinle Formations (USGS, 1969).

Rumors persist regarding the presence of fine-grained disseminated gold in the Mancos Shale, and several operators have applied for mine permits for the bulk testing of this material (UGS, 2002a). However, there has been no indication that the Mancos Shale is host to economic concentrations of gold (UGMS, 1999a; UGS, 2002a). As shown on Map 8, there are four gold mines in Emery County (2 active, 2 inactive) that are operated by Goldterra Inc., or Brenda Kalatzes, but there is no known production from any of these mines. It is possible that some of these gold mining operations may also be working pediment deposits overlying the Mancos Shale.

3.2.7 Gypsum

There are currently four active gypsum mining operations in Emery County, all of which are located on the west flank of the San Rafael Swell (Map 25)(UGS, 2002a). Two additional gypsum mines are currently listed as inactive. The Middle Jurassic Carmel Formation hosts each of these mines, although Summerville Formation may host the Eagle Canyon mine. Pertinent information regarding these six gypsum mines is summarized in Table 14.

Table 14. Gypsum Mines in the Planning Area.

Mine Name	Operator	Status	Loc (Sec., Twn., Rng.)	Notes
Kimbal Draw (San Rafael)	U.S. Gypsum Co.	Active	NW ¼ 21, 23S, 8E	Test shipment of 241 tons in 1999
Eagle Canyon	Georgia Pacific	Active	SE¼ SE¼ 24, 22S, 8E SW¼ SW¼ 19, 22S, 9E	Produced 92,825 tons in 1997 (hosted by Summerville ?)
Hebe	Western Clay Co.	Active	14, 15, 24S, 7E 23, 24S, 7E	Open pit in Carmel covers 41 acres
DKG	Diamond K	Active	NE¼ SW¼ 29, 22S, 9E NW¼ SW¼ 29, 22S, 9E	Produced 16,440 tons in 1998
White Cap #8	Gypsum Resource Development	Inactive	SW¼ 23, 19S, 10E	Inactive since 1994
Whitecloud	Sutherland Brothers	Inactive	15, 24S, 13E	Currently inactive

Source: (UGS, 2002a)

Historically, most of the gypsum mines in the planning area have been small- to medium-sized operations producing between 10,000 and 90,000 tons of gypsum each year using a typical workforce of 2 to 8 individuals (BLM, 1999; UGS, 2002a). However, most of the gypsum resource development in the San Rafael Swell region has occurred since 1990. Conservative gypsum resource estimates on the west flank of the San Rafael Swell are approximately 17 billion tons for the Carmel and Summerville Formations combined (UGS, 2002a; USGS, 1913).

In Emery County, the purity and texture of gypsum deposits vary considerably from pure alabaster-like gypsum of nearly 100 percent $CaSO_4$, to subeconomic resource material that is mixed with significant amounts of silt, sand, and carbonate mud (USGS, 1969). For the purposes of wallboard manufacture, minable gypsum is typically 80 to 95 percent pure. Since gypsum layers are typically tabular deposits within the host formation, mines in the planning area are usually surface operations that excavate the outcrop along strike, and become strip mines by removing the shallow overburden. Because gypsum is a low unit-value, high bulk commodity, the most important factors in evaluating a deposit are its proximity to markets, and ease of mining (USGS, 1990a). Consequently, flat lying, laterally extensive, high grade, and easily accessible gypsum deposits on the west side of the Swell near the Interstate-70 corridor are the most attractive for mining. Most gypsum mines in the western U.S. deliver ore to their mills for $3 to $11 (UGS, 2002a).

3.2.8 Potash and Salt

In 2000, saline evaporite minerals were the third largest contributor to the value of industrial mineral production in Utah with a combined value of approximately $100 million (UDOGM, 2002). Most of this production has come from the surface brines and shallow subsurface deposits in the Great Salt Lake area, and from the bedded evaporites within the Paradox Basin. To the west of the planning area in Sevier and Sanpete Counties, large evaporite deposits also occur in association with diapiric intrusions within the Arapien Shale (USGS, 1991).

While the Paradox Formation has been mined for saline minerals in Grand County (Cane Creek Mine), there are no known current or historic saline mines within the Paradox Basin of southeast Emery County (BLM, 2002; USGS, 1969). This is because evaporite deposits rapidly thin west of the Green River, and overburden thickens under Permian and Triassic sedimentary cover. The northwestern extent of the subsurface potash and salt deposits in the Paradox Basin are shown on Map 19, along with isopach thickness of saline facies.

There is no record of commercial potash production in the planning area (BLM, 2002; UGA, 1990; USGS, 1969). Small saline deposits have also been commercially mined in the Green River and Uinta Formations, but these deposits are all located to the north of the planning area in Duchesne County (USGS, 1969).

3.2.9 Clays

In Utah, bentonite and common clay (as used for brick and tile) are the two most abundant clay commodities. In 2000, six companies produced more than 325,000 tons of common clay and 60,000 tons of bentonite state wide (UDOGM, 2002). Production statistics for other clay minerals are not available, nor are clay production totals from Emery or Carbon Counties. Since the majority of common clay is used for the manufacture of brick, the cyclic nature of the construction industry has a direct affect on the amount of clay that is mined each year in Utah (UGMS, 1991).

While information on clay mining in the planning area is sparse, clay minerals have apparently been commercially mined in five separate regions, all of which are located in Emery County (BLM, 2002; UGMS, 1987; USGS, 1969). These areas are shown on Map 26. Only three bentonite mines are currently active (or recently active) in the planning area that have sporadically produced bentonite over the past several years. These are: 1) the Last Chance Mine operated by Western Clay Company (Sect. 8; T. 25 S., R. 6 E.); 2) the ECDC Mine operated by ECDC Environmental, LLC. (Sec. 1, T. 16 S., R. 11 E.); and, 3) the Powell Bentonite mine (T. 16S., R. 12 E). The Last Chance Mine in southwestern Emery County has produced sodium bentonite from the Cretaceous Mussentuchit Member of the Cedar Mountain Formation, with annual production ranging from 6,000 to 11,000 tons since the mid-1990s (UGS, 2002a). The ECDC Mine in northern Emery County produces bentonite from the Tununk Member of the Mancos Shale for use as liner material at the East Carbon Landfill site (UGS, 2002a). Production statistics from the Powell operation (Map 8) are unknown, but the mine is apparently hosted by the Dakota Sandstone (USGS, 1995a). A bentonite mine was also formerly in production just west of the Green River and south of Interstate 70 (Map 26). However, no other information on these deposits is available. Since 1994, annual production from these mines has varied from as much as 220,000 tons, to zero.

Common clay was reportedly commercially produced from the Triassic Moenkopi Formation on the north end of the San Rafael Swell in central and northern Emery County, and from the Dakota Sandstone and Mancos Shale approximately 12 miles east of Huntington (UGMS, 1987; USGS, 1969). As shown on Map 8, Clay King South (operated by Emery Industrial Development) was an active (as of 12/31/01) common clay mine hosted by the Dakota Sandstone, but its current status is not known. The clay (both common and bentonite) mines in the planning area apparently move from active to inactive status on a relatively frequent basis depending on the market demand for the material.

In addition to commercial clay mines described above, there are a total of 14 community pits and free-use permit (FUP) areas (2 for bentonite and 12 for common clay) in Emery County (BLM, 2002b). The locations of these community pits and FUPs are shown on Map 26. No other information is available on these deposits.

3.2.10 Sand and Gravel

In 2000, sand and gravel (including crushed stone) were the highest contributors to the value of industrial minerals produced in Utah (UDOGM, 2002). These materials were produced in every Utah county by commercial operators; and by federal, state, and local government agencies. Year 2000 production statistics show that 43.7 million tons of sand and gravel, and 8.9 million tons of crushed rock were generated worth a combined value of $168.4 million. While production from individual counties are not available, the vast majority of Utah's sand and gravel is derived from Pleistocene Lake Bonneville shoreline deposits that are not only massive in size, but in close proximity to major urban centers where construction activity is highest (UGMS, 1991).

Within the planning area, there are approximately 117 active (or recently active) sand and gravel pits, most of which are located in Emery County (BLM, 2002, 2002b). The location of these pits is shown on Map 20, all of which are in close proximity to major roadways. As shown on Map 20, most of these pits are hosted by either pediment or recent alluvial deposits, and are small operations producing backfill and borrow for local use only. The Utah Department of Highways is the largest operator of sand and gravel pits in the planning area, followed by the county highway departments. Of the 117 sand and gravel operations in the planning area, 25 are designated as FUPs, 10 for material sale/negotiation, 5 as community pits, and 77 are non-specified pit types (BLM, 2002, 2002b)(Map 20). Mineral material sales or negotiations are essentially over the counter sales of sand and gravel through the Price Field Office.

Past exploration for sand and gravel deposits in the planning area was largely driven by the need to find suitable material for local public works projects. The largest such occurrence was done in support of the Interstate 70 construction in the 1960's. Annual and cumulative production statistics for sand and gravel are generally not available for Carbon and Emery Counties; however, it is known that the Emery County Highway Department and two commercial operators produced approximately 180,000 tons of sand and gravel in 1984 (UGS, 2002a).

Since sand, gravel, and other construction aggregates are generally the lowest priced of all mined mineral products, transportation costs from the pit to the point of end use becomes a major part of their costs to the consumer. As such, even short transportation distances can adversely affect the cost of the final product, and it is imperative that sand and gravel sources be located as close as possible to the point of use, and as close as possible to major roadways.

3.2.11 Stone

There are currently four active commercial rock quarries in the planning area, all of which are located in western Emery County on the Wasatch Plateau where the Tertiary Flagstaff Limestone outcrops (BLM, 2002). These are (Map 37):

1. Dragon Ridge (Sects. 7, 17, 18; T. 18 S., R. 6 E.)
2. The Cap (Sects. 26, 27, 34; T. 18 S., R. 6 E.)
3. Trail Mountain (Sects. 2, 22, 23, 26; T. 17 S., R. 6 E.)
4. Sage Flat (Sects. 2, 16, 21, 28; T. 20 S., R. 6 E.)

Most of this material is quarried for crushed rock, and for use as a mine dust suppressant in local coal mines (UGMS, 1991). The suppressant is a slurry of powdered limestone mixed with approximately five percent silica that is sprayed on the walls and roof of the mine (with or without water) to suppress the dust, to keep the coal from flaking, reduce the risk of explosions, and to reflect more light (USGS, 1987). Some of this material may also be used in the future for flue gas desulfurization in Castle Valley coal-fired power plants. A small portion of the Flagstaff Limestone is reportedly cut for building stone where it is locally oolitic and attractive in color, but most of this type of material is quarried from the Green River Formation at locations north and west of the planning area.

As shown on Map 8, there are two inactive building stone mines previously operated by Quality Building Stone, Inc. on the north end of the San Rafael Swell near Cedar Mountain. These mines, (Red Chief – T. 19 S., R. 10 E. and Snow White – T. 19 S., R. 13 E.) are apparently hosted by the Entrada Sandstone and the Dakota Sandstone, respectively (USGS, 1988). No other information is available on these stone mines.

In addition to commercial stone quarrying operations in the planning area, many of the Triassic and Jurassic sandstone units that outcrop around the San Rafael Swell have been quarried in the past, mostly by private individuals collecting landscape rock under a common use permit issued by the BLM (UGS, 2001a). Good quality building stone and landscape rock can be extracted from the Moenkopi Formation, the Chinle Formation, the Wingate Sandstone, the Kayenta Formation, the Navajo Sandstone, the Entrada Formation, and the Morrison Formation (BLM, 2000; UGS, 2001). Desirable characteristics include a well-cemented, thin-bedded rock with attractive color, texture, and banding.

In addition to the four commercial stone quarries identified above, the BLM permits stone removal at 36 other locations which are designated as follows: 1) 20 FUPs (13 for riprap, 1 for specimen and 1 for dimension stone); 2) 14 community pits (5 for decorative rock and 9 for dimension stone); 3) one mineral material negotiation area; and, 4) one common-use area (BLM, 2002b)(Map 37). As described in Section 1.2, the quarrying of stone from common-use areas or community pits is for noncommercial use only and a permit is required. Blasting is generally not allowed, but some pits allow the use of heavy equipment. Most pits however, allow only hand excavating and loading. The excavation of decorative landscaping stone, or specimen rock, is a popular activity at the following five community pits as advertised in the UGS publication Survey Notes (UGS, 2001a):

1. Old Woman Wash (Sec. 5, T. 25 S., R 13 E.), red sandstone
2. Red's Canyon (Secs. 18, 19; T. 24 S., R. 9 E.), red sandstone
3. San Rafael River (Secs. 19, 30; T. 20 S., R. 9 E.), red sandstone
4. Willow Springs (Sec. 12, T. 24 S., R. 6 E.), basalt boulders
5. Red Seeps (Sec. 12, T. 19 S., R. 9 E.), "pock-marked rock"

In addition to limestone and sandstone, some of the shales and mudrocks that outcrop in the planning area (i.e., Mancos Shale) are potentially amenable for use as a lightweight aggregate for building material if bloated. When heated, bloated shale softens to a plastic state and generates gas through the decomposition of organic matter in the rock. The evolved gas causes the plastic shale to expand, and exhibits a glassy, vesicular texture.

3.2.12 Humate

As of 2001, humate was being mined from the Ferron Sandstone at eight locations (6 active small mine permits and 2 inactive small mine permits) in the Emery coal field just north and south of Interstate 70 (UGS, 1999c, 2002a). Each of these eight mines is located in close proximity to each other, just north of Interstate 70 in southwest Emery County (Map 8). Some may have been abandoned or closed coal mines (i.e., Cowboy Mine). Available information on these mines is summarized in Table 15.

Table 15. Humate Mines in the Planning Area.

Mine Name	Status	Location (¼ ¼ ¼ ,Sect, Twn, Rng)	Year / Production
Rockland (Boddy Toddy)	Active	N½ NW NE, 2, 23S, 6E	1997 / 6,328 tons
No. 1 Clark (Cowboy)	Inactive	S½ SW NW, 2, 23S, 6E	No production
Miller Rock (Bret Clark)	Active	NE SW NW, 26, 22S, 6E	Feb 98 – Feb 99 / 1,000 tons
Daddy Dearest 1-9 (Blackhawk)	Active	SW NE NW, 26, 22S, 6E	1998 / 100 tons
Clark (Emeryide)	Active	SW NE NW, 26, 22S, 6E	1998 / 1,000 tons
T.J. Clark	Inactive	NE NE NW, 2, 23S, 6E	No production
Co-op Placer	Active	NW SE, 3, 23S, 6E	1990-1998 / <20 tons
Walker Flat	Active	SW, 7, 23S, 6E	No production

Source: (UGS, 1999c, 2002a)

Humate mines in Emery County apparently move from active to inactive status on a relatively frequent basis depending on the market demand for the material. Currently, all of the humate being mined in Utah is for use as a nutritional supplement. Humates are being mined in northwestern New Mexico (Upper Cretaceous Menefee Formation) for use as a soil amendment where there is good access to major roadways and rail lines to transport this low unit-value, high bulk commodity (BLM, 1997a).

3.2.13 Miscellaneous Minerals

Miscellaneous mineral occurrences within the planning area include sulfur, barite, cryptocrystalline quartz and other semiprecious gemstones, and silica. While some of these mineral commodities have been mined and produced for a profit in very limited quantities, commercial production has generally not occurred.

There are four or five known sulfur occurrences in Emery County located in the canyon area of the San Rafael River, and to the north on Cedar Mountain. However, these deposits are poorly described in the literature and their locations are uncertain (UGS, 2002a; USGS, 1969). Each of these deposits is undeveloped, and has apparently never yielded any production, but some of them have been prospected with shallow trenches. The occurrence of native sulfur in Emery County is typically associated with warm or cool springs, and commonly occurs as a pale yellow to gray soil cementing material, or in small crystals (UGS, 2002a; USGS, 1969). Information regarding sulfur occurrences in Emery County is summarized in Table 16. Sulfur is currently produced in Utah only as a by-product of smelted metallic sulfides.

Table 16. Sulfur Occurrences in Emery County.

Deposit	Location	Description
Cedar Mountain	Sec. 7(?), T.19S., R.12E.	Native sulfur associated with cool springs. Occurs as soil cementing material.
Mexican Bend	Sec. 2(?), T.21S., R.13E.	Native sulfur in small crystals and as a soil cementing material.
San Rafael Canyon (Sulphur Spring)	Sec.23(?), T.21S., R.13E.	Several small warm springs have deposited native sulfur and travertine along the contact between the Moenkopi and Kaibab Formations.
Black Dragon Canyon	Sec.36(?), T.21S., R.13E.	Small yellow crystals and soil cementing material. Some is black sulfur, probably stained by hydrocarbons.

Source: (UGS, 2002a)

Small quantities of barite were previously mined in southern Emery County where it occurs in association with radioactive minerals in the Triassic Chinle Formation (UGS, 2002a). Barium is used for a variety of industrial purposes including additives for specialty drilling muds.

Cryptocrystalline quartz (including petrified wood along with jasper, agate and chalcedony) is being collected (primarily by rock hounds) from the Moss Back Member of the Chinle Formation, the Morrison Formation, the Cedar Mountain Formation, and the Curtis Formation. Although the collection of dinosaur fossils is prohibited in Utah without a special scientific use permit, plant fossils are collected from several Cretaceous units, and invertebrates (primarily pelecypods and cephalopods) occur in the Mancos Shale.

As noted in Section 3.2.7, portions of the gypsum beds within the Jurassic Summerville and Carmel Formations contain alabaster that is suitable for carving. Several small workings have been opened for alabaster on the east face of Cedar Mountain (UGS, 2002a).

Small amounts of specimen-grade blue celesite ($SrSO_4$), calcite, and barite have been produced since at least 1929 at the Strontium King No. 2 mine in southwestern Emery County (SE¼ Sec. 22, T. 23 S., R. 7 E) which is currently operated by Steven Hatch (UGS, 1999c). The celesite occurs as pale-blue euhedral crystals in veins and fractures that cut the Jurassic Entrada Sandstone host (UGS, 2002a).

Because the Permian White Rim Sandstone; and the Jurassic Navajo Sandstone, Entrada Formation and Wingate Sandstone were deposited in an eolian environment, they are extremely quartz rich and potentially suitable for special silica uses such as foundry sands and glass making which generally require greater than 98 percent silica (U.S. Bureau of Mines, 1988). However, analysis of sandstone samples from these units show high levels of impurities such as iron and aluminum oxides that may preclude their use for these purposes without processing. Because it is poorly cemented with silica, the White Rim Sandstone would be easier and less expensive to process than more firmly cemented quartz sandstone deposits. The same is true for the unconsolidated Quaternary dune deposits that cover large areas in southeastern Emery County, and in small pockets on the San Rafael Swell. In addition, the purity of the Quaternary eolian deposits is high because they were locally derived from multi-cycle sandstones.

4. POTENTIAL FOR THE OCCURRENCE AND FUTURE DEVELOPMENT OF MINERAL RESOURCES

This section of the report discusses the potential for mineral occurrence using the classification system presented in BLM Manual 3031 (BLM, 1985), the level of certainty of that occurrence, and the likelihood that these resources will be developed in the future (especially within the next 15 years) for each mineral commodity discussed in Section 3. A copy of the BLM mineral potential classification system is provided in Attachment 3.

In terms of future development potential, the most important mineral resources in the planning area are coal, coal bed methane, and oil and gas (leasable minerals), gypsum (locatable mineral), clay, sand and gravel, and humate (salable minerals). Overall, coal and coal bed methane resources have the highest potential for future development.

4.1 COAL

As previously noted, The UGS, BLM, and USGS are currently working on a NCRA project to determine the amount of coal remaining for future development in Carbon and Emery Counties. The BLM has determined that the results of this project will become incorporated into this Mineral Potential Report as soon as they are available. Attachment 4 of this document has been reserved for the inclusion of coal resource and development potential information. However, Carbon and Emery Counties contain significant coal deposits that together account for about one-third of Utah's coal resources and 90 percent of its current production.

4.2 COAL BED METHANE

Coal bed methane is probably the single most important mineral resource in the planning area, and its relative significance (as compared to coal) is likely to increase in the coming years. The Bush administration has also made a policy decision to decrease the nation's future dependence on foreign imported oil. Accordingly, the future development of CBM (in addition to oil, conventional gas and coal) resources becomes increasingly likely in areas with high occurrence potential. This section discusses CBM potential separately for the Book Cliffs and Emery Plays, and miscellaneous CBM areas. The occurrence potential for CBM deposits in the planning area is summarized on Map 27.

4.2.1 Book Cliffs (Blackhawk) Play

The UGS recently completed an assessment of the CBM potential for the Book Cliffs area based upon the gas content of coal samples as measured in the laboratory (UGS, 2001). UGS Open File Report No. 176 presents 11 separate maps (A-K) that show regions of favorable CBM recovery potential for each of the major Blackhawk coal seams based upon methane gas concentrations exceeding 5 cc/g. Also shown on the maps are areas where some coal seams have been mined out and are no longer available for CBM production. While the results of this study show that different coal seams are productive for CBM in different geographic regions of the Book Cliffs, the entire northern portion of the play has high CBM occurrence potential from at least one coal seam or stratigraphic interval (UGS, 2001). This area is roughly defined from the outcrop face of the Book Cliffs on the south to the Carbon/Duchesne County line on the north, and from the Price River Canyon on the west, to Sunnyside area on the east. Accordingly, this area of the USGS Book Cliffs Play has a high CBM occurrence potential with a high degree of certainty (Mineral Potential H/D). Coal bed methane occurrence potential is shown on Map 27. Because some of the CBM resources have already been developed (or are under development) in this area, which is accessible by roadways and has gas pipelines already in place (i.e., Questar, Mountain Fuel, and Pacific Gas & Electric), the development of CBM in this portion of the play is considered likely within the next 15 years.

The southeast portion of the USGS Book Cliffs CBM Play in Emery County was not assessed during the UGS 2001 study, and remains largely unexplored for CBM. Furthermore, mine records from the southeast Book Cliffs indicate that Blackhawk coals in this area are non-gassy (UGS, 2001). Consequently, this area is considered to have a low CBM occurrence potential with a low level of certainty (Mineral Potential L/B), and development of CBM resources in the southeastern Book Cliffs is considered unlikely within the next 15 years. Similarly, the northeast corner of Carbon County has a low occurrence potential for CBM resources with a low level of certainty (Mineral Potential L/B) because the area is largely unexplored for coal resources which presumably lie beneath great amounts of overburden. Due to the expense of drilling wells to depths exceeding 4,000 feet, combined with the uncertain nature of the gas accumulations, it is unlikely that Blackhawk CBM resources in the northeast corner of Carbon County will be developed in the next 15 years.

Based on their 1995 assessment, the USGS estimated that approximately 1.94 tcf of CBM gas is probably technically recoverable from the Blackhawk Formation over the entire Book Cliffs Play (USGS, 1995). However, as the CBM industry matures and technology improves, this estimate will likely go up. Gloyn and Sommer (1993) estimated the Book Cliff CBM reserves to be between 4.4 and 5.0 tcf based upon higher estimated gas contents of 10.9 to 12.5 cc/g. However, the UGS considers these estimates overly optimistic because most of the Book Cliffs coal field from the surface to depths of 2,000 feet will be mined or drained of gas by mining, and gas resources below 6,000 feet will be costly to produce (UGS, 2002a). Overall, the UGS estimates that approximately 400 new CBM wells can be drilled in the Book Cliffs Play over the next 10 years. Areas of CBM potential in the Book Cliffs are shown on Map 27.

4.2.2 Emery (Ferron) Play

The Emery CBM Play (Ferron Fairway) has seen extensive development of CBM projects over the past several years with many new wells coming on line each year. With the exception of the Powder River Basin in Wyoming, this area has probably seen more exploration and development of CBM resources than any other region in the United States. Ultimate recoverable gas reserves are estimated to range between 4 and 9 tcf, with approximately 300 bcf of gas already extracted as of the end of 2001 (BLM, 1999; UDOGM, 2002). Developing the entire central portion of the play could eventually support about 3,400 CBM wells drilled on 160 acre centers, with 1,320 of these wells located on shallower eastern portion of the play (up to the Ferron Sandstone outcrop belt), and another 2,080 wells drilled in the deep portions of the play under the Wasatch Plateau and Book Cliffs (BLM, 1997).

The area defined by the USGS Emery Play, including established CBM fields that tap the Ferron Sandstone, have a high CBM occurrence potential with a high degree of certainty (Mineral Potential H/D). However, the eastern portion of the Ferron Fairway, up to the zero isopach line, may actually contain methane gas whose source is the coals beds within the Ferron Sandstone Member, but which accumulated in structural or stratigraphic traps. Accordingly, these deposits may be more accurately classified as conventional gas accumulations rather than CBM deposits. In either case, Philips Petroleum Co. recently decided not to drill some CBM wells they were planning east of Highway 10 in the Drunkards Wash area due to an absence of appropriate coal beds with high gas content (BLM, 2002a). Accordingly, these areas have a moderate CBM development potential with a low degree of certainty (Mineral Potential M/B). In areas of both high and moderate occurrence potential, it is considered likely that these areas of the Emery Play will see development of CBM resources in the next 15 years due to the extensive past and current development in the area, easy accessibility, and the presence of a gas pipeline already in place (i.e., Questar Pipeline Co.) in Castle Valley.

4.2.3 Miscellaneous CBM Areas

The Blackhawk Formation within the Wasatch Plateau coal field appears to have little development potential for CBM within Caron and Emery Counties (UGS, 2002a). In this area, the coal is generally of a lower rank as compared to Blackhawk coal from the Book Cliffs, is often faulted, and has been highly dissected by stream canyons. All of these factors contribute to a low gas content for Blackhawk coals of the Wasatch Plateau field, and corresponding low occurrence potential with a moderate level of certainty (Mineral Potential L/C). Accordingly, it is unlikely that Blackhawk CBM resources in the Wasatch Plateau Field will be developed in the next 15 years.

The northeast side of the San Rafael Anticline remains virtually unexplored for CBM. However, since the Ferron Sandstone Member lacks coal beds in this area where it becomes an entirely marine facies, there is no CBM mineral potential in this area with a high degree of certainty (Mineral Potential O/D). Similarly, because none of the remaining lands in the planning areas are underlain by coal deposits, there is no CBM potential in these areas with a high degree of certainty (Mineral Potential O/D).

4.3 OIL AND GAS

As noted in Section 3.2.3, conventional oil and gas discoveries and associated production has been relatively small in Carbon and Emery Counties despite a 100-year history of exploration and development. While the overall thickness of the Phanerozoic sedimentary section creates ample opportunity for hydrocarbon generation and entrapment, discovery of large fields has not been realized. Nevertheless, exploration continues on a limited basis, focused primarily in areas around existing fields, on subtle structural traps in the Wasatch Plateau, and within the deltaic facies of the Ferron Sandstone. However, the specific location and nature of these exploration targets are generally confidential business information, and are not available to the public. The West Tavaputs Plateau in northeast Carbon County has also been an area of interest due to the abundant source (i.e., oil impregnated) rocks available and the extremely thick sedimentary section; but the uniform, gentle northerly dips of the Tertiary strata are not conducive to structural traps. Favorable closed structures are superimposed on the north end of the San Rafael anticline, but despite these encouraging signs, oil and gas production from these areas has also been a disappointment. Overall, while shows of oil and gas have been relatively widespread across the planning area, large accumulations in economic proportions have not been discovered.

To date, the conventional oil and gas fields discovered in the planning area have been on obvious anticlinal structures with surface expressions. Other accumulations of petroleum may remain to be discovered in subtler structures or stratigraphic traps. Today, the most common exploration methods involve mapping the thickness and structure of individual subsurface beds in search of traps, or performing detailed facies and/or groundwater flow analysis. Some plays, particularly the Uinta Tertiary Oil and Gas (Play 2002), are not confined to structures and may be more continuous type accumulations like the Red Wash of Blue Bell fields further north in the Uinta Basin (UGS, 2002b). In addition, the widespread presence of tar sand, active conventional petroleum fields, and CBM deposits indicate that the strata in northeast Carbon County is charged with petroleum. Other economic deposits of oil and gas may be discovered in the future with a better understanding of source, timing of migration, and migration pathways of the various petroleum systems involved.

With this mind, BLM Handbook H-1624-1, Planning For Fluid Mineral Resources, provides fairly rigid definitions for what constitutes high, moderate and low occurrence potential for conventional oil and gas resources (BLM, 1990). If an area is included within an oil and gas play as defined during the USGS national assessment, then these areas are automatically considered to have a high occurrence potential (BLM, 1990; USGS, 1995). As shown on Map 17, the majority of the planning area except for the San

Rafael Swell region is covered by one or more USGS oil and gas plays, but since there is not overwhelming evidence that economic quantities of oil and gas are present within these areas, there is high occurrence potential with a moderate level of certainty (Mineral Potential H/C). As shown on Map 21, there are several existing oil and gas fields located on the north and northeast flank of the San Rafael Swell that are not included in any of the USGS oil and gas plays (i.e., Grassy Trails, Miller Creek, Farnham Dome, and Woodside). Accordingly, these areas have also been assigned a high occurrence potential with a moderate degree of certainty (Mineral Potential H/C). Overall, it is considered likely that oil and gas resources in these areas will see development over the next 15 years based upon the current demand for energy resources, the existence of pipeline infrastructures, and the overall level of interest among petroleum exploration companies. The Bush administration has also made a policy decision to decrease the nation's future dependence on foreign imported oil. Accordingly, the future development of oil and gas (in addition to coal and CBM) resources becomes increasingly likely in areas with high occurrence potential. The oil and gas mineral potential of the planning area is graphically shown on Map 28.

BLM Handbook H-1624-1 defines areas of low oil and gas potential as areas where there are "specific indications that one or more of the following may not be present: source rock, thermal maturation, or reservoir strata possessing permeability and/or porosity, and traps" (BLM, 1990). Since the rocks of the San Rafael Swell region generally lack only trapping structures (i.e., the tar sand accumulations resulted from erosion of reservoir cap rocks), these remaining areas were assigned a low oil and gas occurrence potential with a moderate degree of certainty (Mineral Potential L/C). In this area, development of oil and gas resources in the next 15 years is considered unlikely.

4.4 SOLID HYDROCARBONS

As noted in Section 3.2.4, Utah's tar sand deposits contain an estimated 25 billion barrels of oil, at least 30 percent of which are located within the planning area (UGS, 1996). In the Sunnyside deposit alone, resource estimates range from a low of about 0.7 billion barrels, to a high of 5.8 billion barrels of oil contained in place. Oil resource estimates for other tar sand deposits within the planning area include 80 to 100 million barrels in the Cottonwood-Jacks Canyon area, and five to 10 million barrels in the Nine Mile Canyon Area (UGS, 1996). Oil resource estimates for other tar sand deposits in the planning area, such as those in the San Rafael Swell area, have not been calculated or remain unpublished due to their spotty, discontinuous nature.

As noted in Section 3.2.4.1, UGMS has identified three occurrence zones of tar sand accumulations based on the thickness and availability of bitumen-rich strata. These occurrence zones are shown on Map 22, and directly correspond to areas of high, medium and low occurrence potential for this resource with a medium level of certainty (Mineral Potential H/C, M/C and L/C). However, because the Sunnyside deposit has been the subject of more thorough investigation as compared to the other tar sand deposits in the planning area, the level of certainty in this area is high (Mineral Potential H/D). Tar Sand mineral potential is shown on Map 29. Due to a lack of available geologic data, areas not assigned a tar sand mineral occurrence potential on Map 29 were not determined (Mineral Potential ND).

As described in Section 3.2.4.2, the northeast corner of Carbon County is underlain by oil shales. These deposits are at least 15 feet thick, and yield an average of 15 gallons of oil per ton of ore rock. There are additional areas in northeast Carbon County that are underlain by low-grade oil shales, or rocks that are unappraised. These areas correspond to regions of moderate and low oil shale occurrence potential, respectively. However, because these areas are based on a less rigorous data assessment than lands east of the Green River where they have been intensely studied, they are associated with a low level of certainty (Mineral Potential M/B and L/B). Oil shale mineral potential is shown on Map 30. Due to a lack of available geologic data, areas not assigned a oil shale mineral occurrence potential on Map 30 were not determined (Mineral Potential ND).

Due to availability of comparatively cheap conventional petroleum, the possibility of developing either tar sand or oil shale resources in the planning area over the next 15 years is unlikely. The major obstacle to production is the lack of an efficient, economical recovery technique that is competitive with oil produced through conventional means. While it is considered unlikely that any of the solid hydrocarbon deposits will be developed in the next 15 years, the Sunnyside tar sand deposits will be the first candidate in the planning area should recovery techniques (particularly in-situ methods) improve, or the price of oil significantly increase, to make extraction economical. However, the richer tar sand deposits in Uintah County will probably be developed long before the Sunnyside deposit. Similarly, oil shale deposits in the planning area are covered by too much overburden for open pit mining, necessitating more expensive underground or in-situ mining (UGS, 2002a). However, even if an efficient and economic recovery process were developed, and oil prices were significantly higher, the thicker and higher grade oil shale deposits in Colorado, Wyoming, and Uintah County would be developed and mined before those in Carbon County.

4.5 URANIUM AND VANADIUM

Due to the radiation that uranium ores emit, they can be easily detected with Geiger counters or similar devices. While this makes prospecting and determining ore concentrations relatively easy and inexpensive, due to the discontinuous nature of uranium deposits (along with their occurrence at depth), resources and reserves are difficult to predict and assess.

The potential for uranium-vanadium occurrence in the planning area is shown on Map 31. Areas where productive mining has previously taken place (i.e., areas that contain mines that have produced in excess of 10,000 pounds of radioactive ore as shown on Map 23), and which coincide with the outcrop footprint of either the Morrison or Chinle formation, are considered to have high occurrence potential with a high level of certainty (Mineral Potential H/D). These regions include the San Rafael River, Temple Mountain, Delta, Tomsich Butte, Sinbad, and Wildhorse mining areas/districts. Other mining regions that contained either small producing mines/prospects hosted by either the Morrison or Chinle Formations have high occurrence potential with a medium degree of certainty (Mineral Potential H/C). These include the Calf Mesa, San Rafael, and Mineral Canyon areas/districts. As shown on Map 23, the West San Rafael and Cedar Mountain Areas are located outside the San Rafael Swell area where most mining of radioactive ores has occurred. These regions contain small mines and/or prospects that are hosted by rock units in addition to the Morrison and Chinle Formations. Regions in these two mining areas that are hosted by either the Morrison or Chinle Formations are considered to have a medium occurrence potential with a high degree of certainty (Mineral Potential M/D), as are all lands outside established mining areas where these two units outcrop. Other areas within the Cedar Mountain West San Rafael mining areas that are hosted by other formations have a medium occurrence potential with a low degree of certainty (Mineral Potential M/B). Because low concentrations of uranium and vanadium are nearly ubiquitous in rocks of all types, the remainder of the planning area is considered to have a low occurrence potential with a low degree of certainty (Mineral Potential L/B).

Due to the continued weak market for uranium, inexpensive supplies of foreign imports, and the lack of any currently operating processing facilities located nearby, it is unlikely that uranium resources in the planning area will be developed in the next 15 years. The total costs for producing uranium from typical Emery County ore (including mining, transportation and milling costs) is approximately $100 to $120 per ton. Using recent uranium prices of $7.10 to $9.60 per pound of U_3O_8, a typical Emery County deposit would contain only $30 to $40 worth of uranium per ton even with 100 percent recovery (UGS, 2002a).

4.6 PRECIOUS AND BASE METALS

As described in Section 3.2.6, and shown on Map 24, the three dominant areas for metals mining and prospecting in the planning area have been San Rafael River, Temple Mountain, and Tomsich Butte/Lucky Strike mining areas. These areas are considered to have a medium occurrence potential with a moderate level of certainty (Mineral Potential M/C). Similarly, the Cedar Mountain mining area located north of the San Rafael Swell, also has a Mineral Potential M/C. However, because each of these areas have been prospected throughout the last century (primarily for copper [with associated silver] and manganese) with very limited success, combined with the fact that ore grades are generally far below what would be required for an economic operation (UGS, 2002a), it is considered unlikely these deposits will be developed in the next 15 years. Most sedimentary manganese ore mined today contains from 35 to 54 percent manganese while the grade of average Emery County ore is 25 percent thus making the deposits uneconomic. In addition, Emery County deposits are small and discontinuous, and could only support a very small operation. While additional undiscovered deposits probably exist in Emery County, there is little economic incentive to explore. A similar situation exists for copper (and associated silver) deposits where mineralized areas are small, discontinuous, and sub-economic in grade. The potential for metals occurrence (other than uranium-vanadium) is shown on Map 32.

Based upon the low concentrations of gold detected in the unconsolidated alluvial sediments along the west bank of the Green River, these areas are considered to have a low metal occurrence potential (principally gold) with a low level of certainty (Mineral Potential L/B). It is unlikely these sediments will be developed as placer mines in the next 15 years due to the low-grade nature of the accumulations, combined with the fine grain nature of the gold, making recovery difficult.

Due to a lack of useful geologic data, the mineral potential for all remaining portions of the planning area was not determined (Mineral Potential ND). This includes the Cretaceous Mancos Shale (which has been rumored to contain fine-grained, disseminated gold, but there has been no published confirmation of these speculations), and the Quaternary pediment gravels which have reportedly been worked as a placer deposit. The potential for metals occurrence (other than uranium-vanadium) is shown on Map 32.

4.7 GYPSUM

Since gypsum beds occur primarily in the Carmel Formation, and to a lesser degree in the Summerville Formation, there is a high and medium occurrence potential, respectively, for this resource where these units outcrop, each associated with a high degree of certainty (Mineral Potentials H/D and M/D).

Map 33 graphically displays the gypsum occurrence potential in the planning area based upon the outcrop extent of the Curtis and Summerville Formations. Also shown on Map 33 is the location of the active (and recently inactive) gypsum mining operations in Emery County. Although gypsum can be found in scattered lenses and nodules within a variety of other sedimentary rock strata, remaining regions of the planning area were considered to have no gypsum occurrence potential with a moderate degree of certainty (Mineral Potential O/C).

As noted in Section 3.2.7, because gypsum is a low-unit-value, high bulk commodity, the most important factors in evaluating a deposit are its proximity to markets, and ease of mining (USGS, 1990a). Consequently, flat lying, laterally extensive, high grade, and easily accessible gypsum deposits are the most attractive for mining. In Utah, major gypsum processing facilities are located in Sevier County near Sigurd, and more extensive deposits occur in the Arapien Shale located outside of the planning area. In addition, gypsum deposits of commercial size and grade are relatively widespread across much of the western United States. However, most of the gypsum mines in the planning area have opened up in the last decade in response to dwindling reserves in the Sigurd, Utah area. The close proximity of the Sigurd processing facilities, combined with good transportation access provided by Interstate 70, make Emery County gypsum deposits on the west side of the San Rafael Swell economically attractive. In general, the gypsum deposits on the west side of the Swell possess low dips, adequate thickness, and good purity to make them suitable for continued mining development. Furthermore, the growing supply of natural gas, and the readily available supply of electricity in Castle Valley make the area an attractive place to site a future wallboard plant (UGS, 2002b). Consequently, it is considered likely that the areas with Mineral Potential H/D will see development in the next 15 years. It is unlikely that the gypsum beds with the Summerville Formation (Mineral Potential M/D) will be developed in the next 15 years.

4.8 POTASH AND SALT

As described in Section 3.2.8, there is no record of commercial saline evaporite production in the planning area. However, areas of subsurface potash and salt deposits associated with the Paradox Basin extend into southeast Emery County (Map 19). Map 19 defines two areas in southeastern Emery County underlain by: 1) major potash zones in the saline facies of the Paradox Formation (Hite and others, 1972); and, 2) bedded halite of the saline facies of the Paradox Formation (Woodward Clyde, 1983). The bedded halite deposits represent the most distal extension of the Pennsylvanian evaporite basin where potash thins rapidly to the northwest. These two areas are considered to have a high potash occurrence potential with a high and medium level of certainty, respectively (Mineral Potentials H/D and H/C). However, because these potash deposits are buried under thick covers of overburden, combined with the presence of competition from more established mines with large reserves located in New Mexico and Canada, it is considered unlikely that Emery County potash deposits will be developed in the next 15 years.

All remaining lands within the planning area are considered to have no potash occurrence potential with a moderate degree of certainty (Mineral Potential O/C). Potash and salt mineral occurrence potential is shown on Map 34.

4.9 CLAY

As described in Section 3.2.8, there is limited information regarding clay production within the planning area. Bentonite and common clay has apparently been commercially extracted from five separate regions within Emery County, and there are four currently active (or recently active) clay mines: 1) the Last Chance Mine; 2) the EDC Mine; 3) Powell Bentonite; and, 4) Clay King South. In addition, there are 14 clay deposits in Emery County that are designated as either community pits or FUPs for resource extraction. All of these areas where clay is being actively mined or extracted have a high occurrence potential with a high degree of certainty (Mineral Potential H/D). Remaining portions of the five general clay regions have a high clay occurrence potential with a low degree of certainty (Mineral Potential H/B). Overall, it is considered likely that the active mining/extraction areas will continue to be developed in the next 15 years, especially the ECDC Mine which supplies bentonite for liner material at the nearby East Carbon Landfill. However, due to the lack of significant nearby markets, it is unlikely that other areas with high clay occurrence potential that are not currently mined will be developed in the next 15 years. Furthermore, most of the bentonite deposits in the planning area are of poor quality, and do not meet the demanding specifications for uses such as oil well drilling. Overall, access to clay outcrops is poor, and is only accessible over unpaved roads (UGS, 2002a). Clay mineral occurrence potential is shown on Map 35.

As discussed in Section 3.2.9, while clay deposits can be found in the Cedar Mountain Formation, the Moenkopi Formation, and the Dakota Sandstone; the Cretaceous Mancos Shale contains large amounts of mudstones and shales through its section, and is considered to have a moderate occurrence potential with a low degree of certainty (Mineral Potential M/B). However, due to a general lack of information regarding these clay deposits, combined with an absence of a significant local market, it is considered unlikely that Mancos clay will be developed in the next 15 years. Since limited or isolated clay deposits can occur in virtually every sedimentary deposit within the planning area, the remainder of Carbon and Emery County was assigned a low clay occurrence potential with a low degree of certainty (Mineral Potential L/B). It is unlikely that these deposits will be developed in the next 15 years.

4.10 SAND AND GRAVEL

Because virtually every unconsolidated geologic deposit is potentially amenable to development of sand and gravel resources, all of the areas mapped as Quaternary sediments, or areas adjacent to modern stream/river courses, have a high occurrence potential with a medium level of certainty (Mineral Potential H/C). However, as shown on Map 20, only those sand and gravel deposits that are located in close proximity to major roadways have been developed for local sources of fill and construction material. Furthermore, it is anticipated that this trend will continue in the future, where it is considered likely that sand and gravel deposits will be developed over the next 15 years only where they are easily accessible to major roadways. Since sand, gravel, and other construction aggregates are generally the lowest priced of all mined mineral products, transportation costs from the pit to the point of end use becomes a major part of their costs to the consumer. As such, even short transportation distances can adversely affect the cost of the final product, and it is imperative that sand and gravel sources be located as close as possible to the point of use, and as close as possible to major roadways.

For other areas hosting unconsolidated Quaternary deposits, but located away from major roads, it is considered unlikely that these deposits will be developed in the next 15 years. These areas include the majority of central Emery County including the San Rafael Swell region. Since thin veneers of unconsolidated material covers much of the ground surface across the planning area, especially areas in the Mancos Lowlands, all remaining lands were assigned a low sand and gravel occurrence potential with a low degree of certainty (Mineral Potential L/B). It is unlikely that any of these deposits will be developed in the next 15 years. Sand and gravel mineral potential is shown on Map 36.

As noted in Section 3.1.10, due to the soft, friable nature of the clasts within most of the pediment deposits, gravels within the planning area are generally unsuitable for concrete or bituminous aggregate. In addition, the increasingly stringent specifications for construction related aggregate material may restrict the amount of local gravel that is suitable for this purpose, and force a shift toward the use of crushed stone, or gravel transported in from outside the planning area. Sand and gravel occurrence potential is shown on Map 36.

4.11 STONE

As described in Section 3.2.11, the Flagstaff Limestone, which outcrops on the north and west margins of the planning area, and the Triassic and Jurassic sandstone units (primarily the Navajo Sandstone and Kayenta Formation) that outcrop around the San Rafael Swell, are all potentially amenable to rock quarrying. However, these rocks generally lack the outstanding visual characteristics typical of these formations at outcrop locations outside of the planning area (i.e., oolitic texture, color banding, striking cross-bedding, etc.) that make them more desirable for commercial quarrying. Consequently, these areas have a moderate occurrence potential for suitable commercial stone with a medium level of certainty (Mineral Potential M/C) (Map 37). However, with the exception of areas where the Flagstaff Limestone outcrops on the Wasatch Plateau, it is considered unlikely that these resources will be developed in the next 15 years due to the lack of unique features in these rocks and nearby buying markets. Due to the presence of nearby coal mines (and the need for mine dust suppressant) on the Wasatch Plateau and Book Cliffs, combined with the potential need for flu gas scrubber material in Castle Valley generating stations, it is likely that the Flagstaff Limestone on the Wasatch Plateau will be quarried in the next 15 years.

Since stone is currently being quarried from a total of 40 locations in Carbon and Emery Counties (4 commercial quarries, 20 FUPs, 14 community pits, 1 mineral material negotiation area, and 1 common-use area),these areas are considered to have a high occurrence potential with a high degree of certainty (Mineral Potential H/D). It is likely that these areas will continue to be quarried over the next 15 years. Stone mineral potential is shown on Map 37.

Since all rock types are potentially amenable to rock quarrying, and there is considerable outcrop across the planning area, all remaining lands were assigned a stone Mineral Potential L/B (Map 37). Other Rock units and their potential use include the Moenkopi, Colton and Green River for dimension stone; the North Horn, Carmel, and Moenkopi for limestone rock dust; and the Mancos, Green River and Colton for lightweight aggregate (UGS, 2002a). Overall, it is considered unlikely that these rocks will be quarried in the next 15 years.

4.12 HUMATE

Abundant humate deposits are intimately associated with coal bearing strata in the Blackhawk Formation, and in particular the Ferron Sandstone. Consequently, the mineral potential for humates is similar to that for coal. However, the future market for humate as an elixir is somewhat in doubt, and this factor, combined with access and marketing problems, will likely inhibit the future growth of this business in Utah. While existing mines are in close proximity to Interstate 70, Ferron outcrops near Emery are far from rail lines making the production of a low unit-value commodity such as a soil amendment less likely to be an economic success as compared to nutritional supplements. Nevertheless, skillful marketing would be required for whatever the end use of the commodity because there are abundant humate resources in the U.S., particularly in New Mexico where there is better access to major roadways and rail lines.

Since all existing humate mines are surface or very shallow subsurface mines in the Ferron Sandstone, areas around the Ferron outcrop belt are considered to have high occurrence potential with a high level of certainty (Mineral Potential H/D). However, for the reasons described above, it is considered unlikely that these humate deposits will be developed over the next 15 years. The exception to this mineral potential and development scenario is along the Ferron outcrop belt immediately to the north and south of Interstate 70 where active humate mining is occurring. These areas have a high humate occurrence potential with a high degree of certainty (Mineral Potential H/D), and it is considered likely that these deposits will be developed in the next 15 years.

Similarly, areas where coal bearing rocks of the Blackhawk Formation outcrop are considered to have a high humate occurrence potential with a high degree of certainty (Mineral Potential H/D). However, since Blackhawk coals have not been previously mined for humate, and large resource supplies are not necessary to satisfy current or anticipated market demand, it is considered unlikely that these deposits will be developed in the next 15 years.

Other areas in Carbon and Emery Counties where the Ferron Sandstone or the Blackhawk Formation are present at relatively shallow depths (approximately 2,000 feet or less) are considered to have a medium occurrence potential with a moderate degree of certainty (Mineral Potential M/C). Areas that are underlain by coal deposits at depths generally exceeding 2,000 feet have a moderate occurrence potential with a low degree of certainty (Mineral Potential M/B). In each of these areas, it is considered unlikely that humate deposits will be developed in the next 15 years. All other lands within the planning area were considered to have no humate occurrence potential with a moderate degree of certainty (Mineral Potential O/C).

4.13 MISCELLEANOUS MINERALS

Miscellaneous minerals that have been previously mined in the planning area include sulfur, barite and semiprecious gemstones (primarily varieties of cryptocrystalline quartz). Since most of the world's sulfur is obtained from the smelting of metallic sulfides, or from the Frasch solution mining method of salt domes, there is no longer a market for the scant native sulfur deposits in Emery County. Similarly, the low-grade barite deposits in Emery County are unsuitable as barium ore, but are currently being extracted at one location for semiprecious gemstones (i.e., celestite). Overall however, due to the lack of information regarding the distribution of semiprecious gemstones in the planning area (e.g., petrified wood, jasper, agate, chalcedony, barite, celestite, fluorite, calcite, and alabaster), the mineral potential for these materials was not determined (Mineral Potential ND).

Because the Permian White Rim Sandstone; and the Jurassic Navajo Sandstone, Entrada Formation and Wingate Sandstone were deposited in an eolian environment, they are extremely quartz rich and potentially suitable for special silica uses such as foundry sands and glass making material. Similarly, the Quaternary eolian dune deposits in southeast Emery County represent a large potential resource of silica sand. Accordingly, these deposits have a high silica occurrence potential with a moderate degree of certainty (Mineral Potential H/C). However, it is considered unlikely that these deposits will be developed in the next 15 years for the following reasons:

1. Extensive sampling and assaying would be necessary to determine if the sands meet the stringent specifications required for foundry or glass sand.

2. Reprocessing would likely be required to eliminate impurities.

3. Transportation problems and expense to process and bring to market.

4. Unproven market.

Other quartz rich geologic units include the Dakota Sandstone and the Kayenta Formation, and areas where these unit outcrops are considered to have a medium silica occurrence potential with a low degree of certainty (Mineral Potential M/B). It is considered unlikely that these deposits will be developed in the next 15 years.

As shown on Map 12, the Digital Geologic Map of Utah (UGS, 2000) does not display individual formations, but groups of rock units because the original map scale was 1:500,000. For this reason, it is not possible to graphically display the silica mineral potential as described above. The closest depiction would be to have map units Qe (eolian sands), Jg (Navajo Sandstone, Kayenta Formation & Wingate Sandstone), and P1 (Cutler Group) shown as Mineral Potential H/C, and map units K1 (Dakota Sandstone and Cedar Mountain Formation), and J1 (Summerville Formation, Curtis Formation, Entrada Sandstone, and Carmel Formation) shown as Mineral Potential M/B. However, since map units K1 and J1 contain units that are quartz poor, only Mineral Potential H/C is shown on Map 38. All other lands within the planning area have no silica occurrence potential with a moderate degree of certainty (Mineral Potential O/C).

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